Central Pollution Control Board
Parivesh Bhawan, East Arjun Nagar, Delhi- 110032

F. No. CP-21/3/2021-WM-II-HO-CPCB-HO 09th March, 2023

OFFICE MEMORANDUM

Subject: Inviting comments/suggestions on "Guidelines for Handling and Management of Jarosite"-regarding

As per the mandate given under footnote of Schedule-I of Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016, CPCB has prepared draft "Guidelines for Handling and Management of Jarosite". The same is available at https://cpcb.nic.in/comment-report1.php.

It is requested that comments/suggestions, if any, may please be communicated by 31st March 2023 at hwmd.cpcb@nic.in or deepti.cpcb@nic.in for finalization of said guidelines.

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Guidelines for Handling and Management of Jarosite Generated from Zinc Manufacturing Plants

February, 2023

CENTRAL POLLUTION CONTROL BOARD
(Ministry of Environment, Forests & Climate Change)
Parivesh Bhawan, East Arjun Nagar DELHI -110 032
Website: www.cpcb.nic.in

Abbreviations

ETP	-	Effluent Treatment Plant
ALT	-	After Lime Treatment
BIS	-	Bureau of Indian Standards
BOD	-	Biochemical Oxygen Demand
CEG	-	Consulting Engineers Group
CETP	-	Common Effluent Treatment Plant
CEZ	-	Canadian Electrolytic Zinc
CIMFR	-	Central Institute of Mines and Fuel Research
COD	-	Chemical Oxygen Demand
CPCB	-	Central Pollution Control Board
CRRI	-	Central Road Research Institute
CUSAT	-	Cochin University of Science and Technology
DMT	-	Dry Metric Tonne
EDL,BZL	-	Edayar Zinc Limited, Binani Zinc Limited
E (P) Act	-	Environment (Protection) Act
EMP	-	Environment Management Plan
ETP	-	Effluent Treatment Plant
F	-	Fluoride
GCL	-	Geosynthetic Clay Liner
GoI	-	Government of India
GW	-	Ground Water
GWT	-	Ground Water Table
HAL	-	Hot Acid Leach
HDPE	-	High Density Polyethylene
HoWM	-	Hazardous & Other Waste (Management & Transboundary Movement) Rules, 2016
HW	-	Hazardous Waste
HZL	-	Hindustan Zinc Limited
IISc	-	Indian Institute of Science
IRC	-	Indian Roads Congress
ISF	-	Imperial Smelting Furnace
JCF	-	Jarosite Containment Facility
Kg	-	Kilogram
Km	-	Kilometer
LCS	-	Leachate Collection System

LOI	-	Loss on Ignition
Mg	-	Magnesium
MIC	-	Metal in Concentrate
MINAS	-	Minimal National Standards
Mn	-	Manganese
MoEF&CC	-	Ministry of Environment & Forests & Climate Change
MT	-	Metric Tonne
mT	-	million tonne
NAAQS	-	National Ambient Air Quality Standards,
NCCBM	-	National Council for Cement and Building Materials
NHAI	-	National Highway Authority of India
NL	-	Neutral Leach
Pb	-	Lead
PCC	-	Pollution Control Committee
PG	-	Jarosite
Ppm	-	parts per million
PUCC	-	Pollution Under Control Certificate
PW	-	Prime Western
RLE	-	Roast Leach Electrowin
RRL	-	Regional Research Laboratory
RSPCB	-	Rajasthan State Pollution Control Board
RSRDC	-	Rajasthan State Road Development Corporation
SHG	-	Special high Grade
SLF	-	Secured Landfill
SPCB	-	State Pollution Control Board in State
SPM	-	Suspended Particulate Matter
STLC	-	Soluble Threshold Limit Concentration
TDS	-	Total Dissolved Solids
TCLP	-	Toxicity Characteristics Leaching Procedure
TPA	-	Tonnes per annum
WMT	-	Wet Metric Tonne
Zn	-	Zinc
ZnS	-	Zinc Sulphide

Table of Content

List of Tables

List of Figures

Chapter 1: Introduction

Jarosite is a solid residue generated during the production of zinc from its ore, by adopting hydrometallurgical or pyro-metallurgical operations. It is a crystalline and easily filterable residue generated during precipitation of iron in the leaching process of zinc, which is usually washed to recover zinc. The resultant solid iron residue (in jarosite process) consists of oxides of iron, sulphur and zinc. The jarosite (iron residue) is classified as high volume low-effect waste as per the provisions under Hazardous and Other Waste Management Rules, 2016 (HWM Rules) and required to be disposed as per the guidelines prescribed by Central Pollution Control Board (CPCB). Jarosite may also be characterized as per the waste classification schedule given under HWM Rules as given at ***Appendix I***. Iron residue can be separated adopting Jarosite, the Goethite and the Haematite Processes, however this report highlights environmental management aspects of Jarosite based iron residue commonly adopted by operating plants in the country.

Jarosite generated from zinc smelters has acid leaching potential hence requires to be stabilized prior to storage and utilization. The acidic leaching characteristics of Jarosite can be converted into a stabilized(fixed) form by treating with lime and cement. Industry may adopt suitable stabilization methods so that the leaching potential is reduced as per the criteria given in this guidelines. Stabilized Jarosite adopting one such methods of stabilizing Jarosite is common known in Industry as Jarofix [1]. Stabilized (fixed) Jarosite has the potential to be utilized for the construction of road embankment, while mixture of stabilized Jarosite and soil (50-75%). Stabilized-Jarosite and bottom ash mix (50-75%) have the potential to be utilized for the construction of embankment and may be used for construction of sub-grade layer of road pavement.

These guidelines are prepared to address the overall aspects of Jarosite handling, storage and disposal including its utilization. The report also gives present scenario of zinc smelting, generation of Jarosite, and current practices of handling and management of jarosite in the country. The report also deals with the guidelines to be followed for safe handling, transportation, storage of Jarosite within the zinc smelters, safe disposal of Jarosite through different methods, end use of Jarosite for beneficial use that may be encouraged in order to address the potential environmental risks associated with the disposal of Jarosite.

The guideline also deals with ways and means to avoid or minimize the generation of Jarosite as well as to treat Jarosite so as to minimize the potential environmental impacts. In addition, the report deals with Jarosite stock lying at closed smelters.

1.1 Applicability

These guidelines are applicable to:

a) All existing operational zinc smelters which are generating Jarosite as iron residue.
b) Expansions of existing zinc smelters proposing to generate Jarosite as iron residue.
c) New zinc smelters proposing to generate Jarosite as iron residue.
d) Zinc smelters which have now got closed but historically generated Jarosite during their operational lifetime.

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[1] Industry may adopt any effective stabilization method that meets the criteria given in these guidelines. CPCB does not endorse any Patent of stabilization in the name of 'Jarofix'

e) Zinc smelters which have now switched completely to non-Jarosite options but generated Jarosite in the past and still have Jarosite disposal facilities on-site (or off-site but legally the smelter's responsibility).
f) Orphan sites having Jarosite storage and/or disposal facilities.
g) All stages of Jarosite handling, viz., the point of generation, treatment, interim storage, transportation (both on-site and off-site) up to disposal.
h) Users of Jarosite.

Note: *These guidelines are not applicable to other zinc residue options, viz., goethite/ paragoethite, haematite, neutral leach residues, pyro-metallurgical options for residue treatment and disposal, etc.*

Chapter 2: Zinc and Its Manufacturing Process

2.1 Zinc and its applications

Zinc is the most abundant element on earth's crust, it is normally found in association with other base metals such as copper and lead in ores. It is more likely to be found in minerals together with sulfur and other heavy chalcogens. Sphalerite, is zinc sulfide containing ore commonly mined ontains 60–62% zinc. Worldwide, 95% of new zinc is mined from sulfidic ore deposits, in which sphalerite (ZnS) is nearly always mixed with the sulfides of lead, iron and copper.

Other source minerals for zinc include smithsonite (zinc carbonate), hemimorphite (zinc silicate), wurtzite (another zinc sulfide), and sometimes hydrozincite (basic zinc carbonate). With the exception of wurtzite, all these other minerals were formed by weathering of the zinc sulfides.

The estimated world zinc resources are about 1.9–2.8 billion tonnes. Large deposits are in Australia, China, Peru, Mexico, Kazakhstan, United States, and to some extent in India. Global zinc mine production in 2018 was about 12.7 million tonnes, with China accounting for 33% and India 6%.[2]

Zinc is an elemental metal primarily used for corrosion resistant coating of iron. Zinc is also used in production of electrical batteries, small non-structural castings, and alloys such as brass. One of its compounds such as zinc oxide is used as an additive in tyres and other rubber compounds. Zinc is also used as dietary supplement (such as zinc carbonate and zinc gluconate), deodarents (zinc chloride), anti-dandruff shampoos (as zinc pyrithione), luminescent paints (zinc sulfide), and its organic compounds have laboratory use.

Zinc is also an essential nutrient, including to prenatal and postnatal development. Zinc deficiency affects about two billion people in the developing world and is associated with many diseases. Consumption of excess zinc may cause ataxia, lethargy, and copper deficiency.

2.2.1 Zinc occurrence and mining in India

Total mineral resources for zinc in India, as on 1st April 2015, were approx. 36 million tonnes of contained zinc, out of which approx. 10 million tonnes were in reserves category. More than 90% of these resources and almost 100% of the reserves were in the state of Rajasthan.

Zinc mine production in India was accounted entirely by the company named Hindustan Zinc Limited (HZL), a private sector company with significant shareholding by GoI. The total production of metal in concentrate (MIC) during the year 2018-19 was 728,498 tonnes. All the mines of HZL are located in the state of Rajasthan. Details of mines and production therefrom are provided in **Table 1**. The detailed analyses of concentrates from these mines are provided in **Table 2.**

Table 1: Production of zinc concentrates in India

Year	Hindustan Zinc Limited, MIC (MT)					Total
	Rampura Agucha Mine	Sindesar Khurd Mine	Zawar Mine	Rajpura Dariba Mine	Kayad Mine	
2014-15	1378113	180738	74186	54006	3720	1690763
2015-16	1288993	269373	102987	74315	7601	1743269
2016-17	1231342	300213	113014	79861	10000	1734430
2017-18	1158114	467949	123281	99262	12000	1860606
2018-19	987835	537543	174954	114841	11995	1827168
2019-20	413085	255151	125436	37272	77633	908577
2020-21	413226	226622	135492	34506	60783	870629

Source: HZL

Table 2: Chemical composition of Indian Zinc Concentrates

	Mines (Hindustan Zinc Limited) (weight % - dry basis)												
	Rampura Agucha (2017-19)			Sindesar Khurd (2017-19)			Zawar (2017-19)			Rajpura Dariba (2017-19)			Kayad
Year	**17**	**18**	**19**	**17**	**18**	**19**	**17**	**18**	**19**	**17**	**18**	**19**	
Zn	50.45	49.44	49.77	50	50.1	48.78	55.04	52.25	51.52	47.01	48.31	46.69	INP
Fe	9.57	9.17	9.19	9.89	10.02	9.95	6.19	7.1	7.22	9.9	8.13	8.84	INA
SiO_2	3.58	4.09	3.77	2.84	1.96	2.49	1.02	1.74	1.6	5.2	4.81	4.64	INA
Pb	1.21	1.60	1.46	2.03	2.12	2.15	1.84	1.77	2.59	1.29	2.07	2.11	INA
S	29.60	29.58	29.78	30.70	30.40	30.36	30.2	30.56	30.52	30.00	30.25	29.80	INA
Cu	0.1282	0.1233	0.1198	0.0896	0.1095	0.0978	0.0340	0.0558	0.0515	0.0942	0.0933	0.1040	INA
Cd	0.1457	0.1480	0.1494	0.2871	0.298	0.2952	0.2748	0.2349	0.2583	0.3429	0.3644	0.3496	INA
As	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	INA
Mn	0.1519	0.1384	0.142	0.4558	0.4926	0.4988	0.0472	0.0488	0.0407	0.2997	0.2515	0.1887	INA
Hg (ppm)	36.12	38.2	37.01	74.24	69.12	75.13	37.9	40.52	36.16	285.15	243	292.5	INA

Source: Hindustan Zinc Ltd.
INA- Information Not Available
BDL: Below Detection Limit

2.2.2 Zinc metal Production

Zinc is the fourth most common metal in use, trailing only iron, aluminium and copper; with global consumption of about 13.7 Million Tonnes (MT) and production of about 13.2 MT during 2018. China is the leading producer of the metal (4.53 MT) with about 34% of the world production, while India produced 696,283 tonnes during 2018-19. The entire Indian primary zinc production is currently coming from Hindustan Zinc Limited. Another company, viz., Binani Zinc Limited (BZ L), now known as Edayar Zinc Limited, had a smelter in Kerala which closed its operations in 20146. In addition, there are a few secondary producers of zinc. Details of primary zinc production from different smelters are provided in **Table 3.**

Table 3: Zinc production in India

	VZS	Hydro 1	Hydro 2	Dariba	Debari	Binani
2013-14	NIL	NA	NA	NA	NA	4477
2014-15	NIL	NA	NA	211725	69384	NIL
2015-16	NIL	193639	207923	219256	68349	NIL
2016-17	NIL	173401	178424	203530	48301	NIL
2017-18	NIL	196179	214465	230837	76979	NIL
2018-19	NIL	191188	209290	219625	NA	NIL

Source: M/s Hindustan Zinc Ltd & M/s Binani Zinc Ltd.

2.2 Zinc Manufacturing Process

Zinc concentrate is used in production of zinc, which is obtained by concentrating sphalerite using the froth flotation method. The concentrate may also contain secondary or recycled zinc material.

There are two process routes for zinc production from zinc concentrate: hydrometallurgical (conducted in aqueous solution) and pyrometallurgical (largely conducted using high temperature processes producing zinc in liquid form). The hydrometallurgical route is also called the electrolytic process. Large amount of energy is consumed in zinc production process.

Production process routes generally require an (i) oxidation stage (roasting or sintering) to remove the sulphur present in the concentrate, (ii) a reduction stage (electrolysis, blast furnace, electro-thermic furnace or vertical retort) to reduce the oxide phases back to metallic form, and (iii) a refining stage to remove impurities. These stages and their order are presented in **Table 4.**

Table 4: Process stages in the production of zinc

	Production Process			
Process stage	**Electrolytic**	**Imperial Smelting**	**Electro thermic**	**Vertical Retort**
Oxidation	Roasting Leaching	Sintering	Roasting and/or Sintering	Roasting
Refining	Solution Purification	-	-	-
Reduction	Electrolysis	Blast Furnace	Electric shaft (or Electric Arc)	Vertical Retort
Refining	-	Distillation	Distillation	Distillation
Natural Product	Special High Grade (SHG)	Prime Western (PW)	Prime Western (PW)	99.5% Zinc
Residue	Leach Residue	Slag	Slag	Retort Residue (generally a slag)

Globally, out of a total production capacity of approximately 14 MT of zinc, more than 95% is based on hydrometallurgical technology. Only eight large smelters are operating on pyrometallurgical route globally - two on Vertical Retort route (both in China) and six on Imperial Smelting (03 in China, 01 in India now producing only lead, 01 in Japan and 01 in Poland) with combined capacity of less than 0.7 MT of zinc per annum; in addition, some small smelters based on retorts or electro-thermic routes are operating in China.[7]

From **Table 2**, it can be seen that zinc is normally associated with lead, has silver as valuable associated by-product metal, and a number of associated "co-elements" that may include valuable potential by-products (like Cd, Cu, Co etc.) but mainly comprise impurities and waste elements which must be removed and end up in residues and emissions.

2.3.1 Electrolytic Process

A simplified flow sheet of a typical electrolytic zinc smelter is given in **Figure 1**. This route is also known as Roast - Leach - Electro winning (RLE) route.

The object of roasting is to convert the zinc sulphide in the concentrate to zinc oxide, which can be leached by a sulphuric acid solution. The roasting reaction proceeds rapidly in the temperature range 850 - 1000°C and generates enough energy to make it autogenous. A small amount of sulphur (typically 2%) remains in the calcine product mainly as sulphate but partly as unreacted sulphide. A majority of zinc smelters adopt fluid bed roasters. Most impurities in the concentrate leave the roaster with the calcine, chlorine, fluorine, mercury and selenium being important exceptions. Mercury and selenium will report to the acid produced from the sulphur dioxide in the waste gas if they are not removed at the gas cleaning stage.

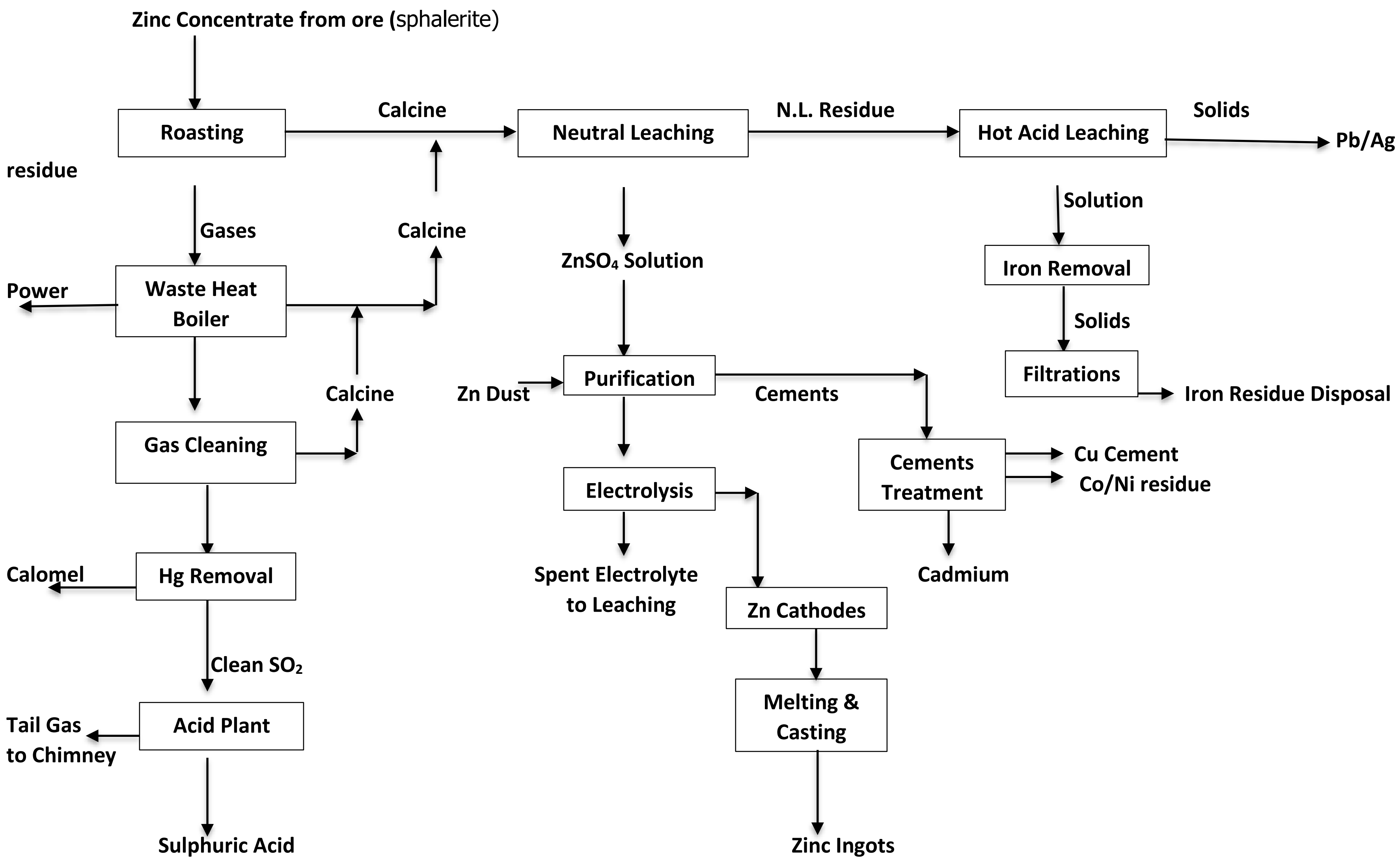

Figure 1: Process Flow Sheet-Zinc Smelter

The principal roasting reactions are as follows:

$2ZnS$ (zinc sulphide)	+	$3O_2$	→	$2ZnO$ (Calcine)	+	$2SO_2$	+	223.6 Kcal
$4FeS$	+	$7O_2$	→	$2Fe2O3$	+	$4SO_2$	+	Heat
ZnO (Calcine)	+	Fe_2O_3	→	$ZnOFe2O3$ (zinc ferrite)				

Approximately 90% of the zinc in roaster calcine is in the form of zinc oxide, with the balance being present as zinc ferrite, an iron-zinc oxide ($ZnO.Fe_2O_3$). Zinc oxide can be leached with weak sulphuric acid solutions, but leaching the zinc from ferrites requires more aggressive acid conditions. Unfortunately, these leaching conditions also dissolve the iron, which must subsequently be removed.

"Residue Treatment" is the traditional name given to the processes to further treat neutral leach residues to obtain a higher zinc recovery. Normally the processes will consist of further hydrometallurgical treatment steps commencing with hot acid leaching and continuing with an iron removal step. Several zinc smelters, however, use a pyrometallurgical process for further treatment.

The liquor from the hot acid leach stage goes for iron removal and the solids are generally filtered to form one of the major residues produced by electrolytic zinc smelters. This hot acid leach residue contains majority of lead, silver and gold as well as some of the gangue constituents of the concentrates, mainly silica. Depending on the content of these precious metals, this residue is treated further to produce a lead and/or silver concentrate, otherwise stored/dumped on site.

A small number of zinc plants have a pressure leach circuit that converts zinc concentrate directly to zinc sulphate solution that can join the neutral leach overflow from conventional leaching. This process is being used at a few smelters in Canada. Some smelters also leach concentrates directly at atmospheric pressure.

a) Mercury Removal System (Calomel Process)

The calomel process was originally developed for the purpose of removing mercury vapour from zinc concentrates roaster gases, after these gases have been treated in the conventional cleaning, washing and cooling plant.

The reactor for removal of mercury treats gases at a temperature of 380C. The reactor is a counter current absorption tower made of glass fiber reinforced plastic. The tower is packed with plastic rings made of polypropylene. The $HgCl_2$ solution is sprayed over the packing by nozzles. The mercury vapour comes in contact with mercuric chloride solution and transforms to mercurous chloride. When mercury content in circulating water increases, some of the mercurous chloride is taken to a chlorination tank to conversion to mercuric chloride, which is used as make-up in circulating water. The mercurous chloride (calomel) is withdrawn periodically and stored for sale to interested buyers. The main reactions are as follows:

$$HgCl_2\ (l) + Hg0\ (gas) \rightarrow Hg_2Cl_2\ (s)$$

$$Hg_2Cl_2\ (s) + Cl_2\ (gas) \rightarrow 2\ HgCl_2\ (l)$$

b) Iron Removal

There are three processes to remove the iron from the hot acid leach solution, the Jarosite, the Goethite and the Haematite Processes, named after the iron compound that is produced. There are also variants of these processes that have been adapted for economic reasons particularly if a separate lead-silver residue is not required.

The principal aim of each iron removal process is to place the conditions of temperature and acidity in the target range for the desired compound.

c) The Jarosite Process

Jarosite can be precipitated as ammonium, sodium or potassium Jarosite. Sodium Jarosite has the formula $Na_2[Fe_6(SO_4)_4(OH)_{12}]$. Apart from iron, it withdraws sulphur from the circuit.

The typical reaction for the formation of Jarosite (ammonium Jarosite shown) is:

$$3Fe_2(SO_4)_3 + 10H_2O + 2NH_4OH = 2NH_4Fe_3(SO_4)_2(OH)_6 + 5H_2SO_4$$

The optimum conditions for Jarosite precipitation are pH1.6 and 920C. Calcine is added to neutralize surplus acidity. Following reaction in a series of tanks, the slurry is thickened and the Jarosite residue, after filtration, goes for disposal. Jarosite contains approx. 25-30% Fe and is the most popular of all the iron removal processes as it offers high recoveries (96-99%) in a simple process with the option of lead-silver separation. Its main drawback is a bulky residue whose safe handling and disposal from an environmental perspective is difficult and costly.

d) The Goethite Process

In this process, the iron is reduced to ferrous state using zinc concentrates. In the second step the acidity is reduced to 2g/l using calcine in a pre-neutralization stage. The goethite precipitation takes place at 900C and pH 2.5-3.5. Goethite, FeO.OH, contains about 40% Fe and therefore occupies less storage space than Jarosite. It contains low levels of Sulphur compared with Jarosite.

Goethite precipitation is in accordance with the following reaction:

$$2FeSO4 + O_2 + 3H_2O = 2(FeOOH) + 2H_2SO_4$$

In a variation of the Goethite Process, producing paragoethite, the reduction stage is omitted saving significant costs, and neutralization is carried out using Waelz oxides. The residue, whilst similar to goethite, hence the name paragoethite, contains a slightly different chemical formula including a small amount of sulphate.

Zinc recovery from the Goethite Process at 92-96% is always less than that obtained from the Jarosite Process and the operating costs are higher. Its main advantages are the reduction in residue volume compared with Jarosite, and the potential for an easier smelting route if this is subsequently decided upon. A further advantage is that some problem minor impurities, in particular germanium and fluorine, are removed more easily, because the iron hydrolysis is carried out at a higher pH than for the Jarosite Process.

It should be noted that in the precipitation of goethite, paragoethite and Jarosite, the final residue is not 'pure'. Jarosites will contain a number of different species in minor amounts and also goethite. Similarly, goethite will contain other iron species that include Jarosite and other iron hydroxysulfates. The assertion that 'Jarosite' is stable should be cautioned, as some of the minor iron precipitates may not be so and thus contribute to the overall environmental unacceptability.

e) The Haematite Process

In the Haematite Process, developed by Akita Zinc at Iijima, the ferric iron is first reduced to ferrous, as for the Goethite Process, using zinc concentrate, and the excess acidity is neutralised either with limestone or with calcine. The solution is then treated in autoclaves at 1800C under a pressure of 18 atmospheres using oxygen.

Haematite is precipitated as alpha-Fe2O3 and contains 50-60% Fe and a residual zinc content of 0.5-1.0%. Achievable zinc recoveries can be as high as 98%. The high recoveries of precious metals make the Haematite Process unique amongst the electrolytic residue treatment routes.

Only Iijima now operates the Haematite Process and it is technically complex and expensive. Iijima is able to sell the residue, which is the major potential advantage of the process. Others have considered and rejected it because it cannot meet steel plants' stated needs for zinc and sulphur levels to be less than 0.01% and 0.005% respectively.

f) The Future of Hydrometallurgical Residue Treatment

Over the past few years, many smelters have reviewed their residue options, primarily on account of the environmental concerns related to their storage and disposal, including the land occupied for the purpose. Some, including the new smelters in India, have adopted the process of stabilizing(fixing) Jarosite (with 10-15% cement) as an acceptable route.

For many other smelters, decisions for change will have to be faced in the future. The fundamental objectives must be:

- To produce an iron product that is either usable or disposable in a non-hazardous form.
- To avoid the by-production of other hazardous wastes, even in small quantities.
- To recover economically high proportions of the zinc, lead, cadmium, copper and precious metals in the raw materials.
- To minimize capital and operating costs.

g) Solution Purification

Neutral leach solution contains dissolved impurities such as cadmium, copper, cobalt, nickel, calcium, magnesium, manganese and chloride. Small amounts of magnesium, manganese and chloride are not harmful but excessive amounts can only be eliminated by operating a bleed from the circulation system. Calcium is not harmful, as such, but most circulating solutions are saturated and gypsum deposits are formed whenever the solution is cooled. This leaves the most important impurities that could affect the quality of zinc product from electrolysis (the first four), which are removed by cementation with zinc dust, zinc being less noble than the metals requiring removal. In this process, the zinc dissolves and the more "noble" metals come out of solution as a solid.

Different plants use different sequences of impurity removal by varying conditions of temperature, time and acidity, and the use of activating chemicals. The two most common sequences are: -

- The co-removal of copper and cadmium in a cold treatment using zinc dust, followed by the co-removal of cobalt and nickel in a hot treatment assisted by the addition of antimony trioxide.
- The co-removal of copper, nickel, cobalt and arsenic in a hot treatment using arsenic trioxide as an activator followed by cold treatment using zinc dust alone to remove cadmium.

In both sequences, there is normally a final polishing stage using zinc dust and a small amount of copper sulphate. The choice of sequence is generally made on the content of different impurities in the raw materials and the desired residue products. At one or two plants, cobalt and nickel are removed without the use of zinc dust but by using organic chemicals.

Often the cadmium will be further treated by re-dissolution, concentration and electrolysis to a saleable cadmium product and the other residues will be sold for recovery of byproducts.

h) Electrolysis

The solution from the purification stage is fed as a make-up to the electrolyte circulating through the tank house cells, which have lead-silver anodes and aluminium cathodes. An electric current is passed between the anodes and cathodes resulting in pure zinc being deposited on the latter and oxygen being evolved at the former. Electrolyte is re-circulated to the cells and, because it heats up during the electro-deposition process, it is cooled to 27-30°C in forced ventilation cooling towers before being returned to the circuit. A portion of spent electrolyte, balancing the volume of the incoming purified leach solution, is bled off and routed to the neutral leach circuit.

At regular intervals of 24-72 hours, depending on the design of the tank house, the cathodes are removed from the cells and the zinc deposit stripped from the aluminium blanks. Traditionally, cathodes were removed from the cells using manually operated hoists and the zinc deposit manually stripped from the aluminium blanks. Modern trend is for mechanization of the stripping process and to the complete automation of the cathode removal and stripping process, leading to higher productivity and less damage to electrodes, which retain their flatness better and are therefore less prone to short circuits.

i) Residue Disposal

Disposal of residues is becoming increasingly important for electrolytic zinc smelters, primarily on account of associated environmental concerns and related cost implications.

The hot acid leach (HAL) residue, if produced, contains the majority of lead and precious metals contained in the concentrates treated. In general, this residue is treated elsewhere for recovery of lead and precious metals. If a neutral leach residue is produced, it contains lead and precious metals as well as a significant amount of unleached zinc. The normal treatment routes for both types of residue are via pyrometallurgical route (ISF zinc smelters and lead smelters).

Storage of iron residues is usually in ponds lined with an impervious membrane. Concerns with this method of disposal have increased with greater environmental awareness mainly relating to the possibility of the ponds leaking and groundwater being contaminated with heavy metals leached from the iron residue.

Other options for residue treatment are being investigated and developed which include: hematite, which can be used as a source of iron in cement plants or steel plants, goethite/paragoethite which can be pyrometallurgically treated for recovery of zinc and other by-products and slag as final residue for civil engineering applications. Jarosite stabilization process uses cement to stabilize the residue.

Further discussion of residue treatment & disposal options can be found in **Appendix 2.**

2.3.2 Pyrometallurgical Route

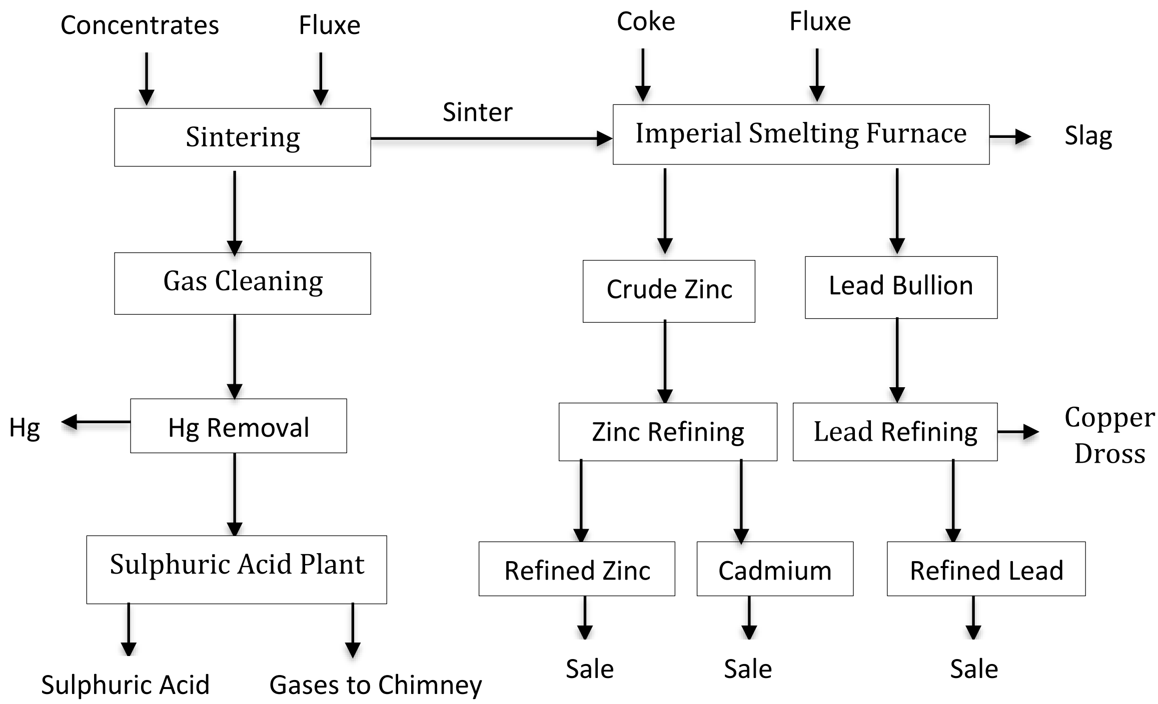

Figure 2: Simplified Flow sheet for Typical ISF Zinc Smelter

a) Sintering

The purpose of the sintering process is to convert finely ground sulphide concentrates (or oxidic calcines in the case of an electrothermic plant) to a lump form suitable for treatment in a shaft furnace. In the case of sintering sulphide materials, sulphur needs to be burnt and eliminated, and this provides the heat needed for fusion. For the sintering of calcine, heat is provided by adding coke breeze to the sinter machine charge.

Zinc sintering for the electro- thermic furnace or for vertical retorts is carried out on a downdraft sinter machine, while zinc-lead sintering for an ISF plant, like lead sintering, requires an up-draft machine to prevent the slumping and blinding of the bed and grate that would be caused by molten lead and lead oxide.

Product sinter is broken to a suitable size for the shaft furnace, typically 100mm, while natural fine material, together with crushed sinter to make up the feed to the sinter machine, are re-circulated and used as a diluent for sulphur in new feed to the process.

b) Blast Furnace (Imperial Smelting Furnace - ISF)

The Imperial Smelting (ISF) blast furnace simultaneously smelts zinc and lead oxides to their metals using high quality metallurgical coke as the energy source. The zinc leaves the furnace in the of gas as a vapour. The lead-splash condenser rapidly cools and dissolves the zinc vapour in a spray of molten lead. Lead in the charge is recovered, together with copper, in lead bullion, which also carries precious metals from the charge. It is tapped from the furnace bottom with slag that contains the gangue components. After separation, slag is generally stockpiled on site but can be used for civil engineering applications.

Product zinc contains about 1.2% lead and minor levels of cadmium, arsenic, iron, copper and tin which require removal by distillation at the refinery. Lead bullion, still containing copper and precious metals, or following copper dross removal, passes to a lead refinery for refining.

c) Electro-thermic and Electric Furnaces

The electro-thermic process involves a vertical shaft furnace in which the heat required is generated by electrical resistance heating through the charge, power being supplied through carbon electrodes. Coke is used as reductant. Zinc oxide in the charge is reduced and zinc vapour collected in a zinc condenser.

Sterling Process, developed to treat oxide concentrates from the Sterling Hill mine, generated higher temperatures by arc and slag resistance, the entire charge being completely melted. The electric furnace process more recently developed and promoted in China is similar and is intended to provide a simple smelting route for small smelters and to encourage the replacement of old polluting processes. It has a distinct advantage over the electro-thermic furnace in that, not involving a shaft, oxide feed can be in the form of dust and does not require an agglomeration step.

d) Vertical Retort Process

Mostly operating in China, the vertical retort process uses calcined zinc concentrate, either sintered or roasted, which is then briquetted with coal and a binder. The briquettes are charged hot to a vertical shaft, constructed of silicon carbide bricks, which is externally heated usually using producer gas. Zinc is reduced and volatilized and is then condensed in a zinc- splash condenser. Because the zinc is not absorbed into lead and the upper part of the retort eliminates lead back into the charge, the product is 99.5% zinc, with lead levels of less than 0.2%. This product can be used directly for a number of applications without further refining, although it may require removing cadmium in distillation columns. The retort residue is withdrawn from the bottom of the retort and dumped. In China, the residue is used to make bricks.

e) Refining

The zinc from the ISF contains approximately 98.5% Zn, up to 1.4% Pb, and 0.1 to 0.3% Cd. Generally, there is too much cadmium in the zinc to be sold without further refining. Vertical retort zinc (99.5%) also contains high cadmium.

Refining is done by the traditional New Jersey distillation method in columns fitted with silicon carbide trays. Heat is provided by oil, natural gas, propane or butane, and in some plants, partially by LCV gas. In Chinese vertical retort smelters, coal is often used to produce coal gas, which is then used for heating both the vertical retorts and the refining columns.

f) Comparison of hydrometallurgy and pyrometallurgy

Having understood the details of hydrometallurgical routes for zinc extraction vis-à-vis pyrometallurgical ones, it will be useful to understand the reasons for popularity of hydrometallurgical routes for zinc extraction from its concentrates. The summary of different parameters and how the two routes broadly fare against each of them is as below:

Criterion	**Hydrometallurgy**	**Pyrometallurgy**	**Remarks**
Product Quality	Special High Grade(SHG)	Prime Western (PW)	PW has limited applications
Tolerance to impurities in raw materials	Dependent on removal capacity	Generally more tolerant	
Energy Costs	Mainly electric power, localized costs	Higher costs of coke	China is exception
Raw Material Flexibility	Need cleaner zinc concentrates	Can accept 'dirtier' raw materials	Mines are supplying cleaner materials
Recoveries	Higher zinc recoveries; poor precious metal recoveries w/o a lead residue. Capacity to recover minor elements (In, Ga, Ge)	Better recoveries of lead, precious metals	
Residue production	Environmental concerns regarding disposal	Slags	Slags better from environmental perspective

Hydrometallurgical smelters are better amenable to more reliable operations and process control. This combined with higher zinc recovery, better product quality, and availability of clean zinc concentrates, is the reason for hydrometallurgical route being most popular for zinc extraction. Within that, Jarosite is the most popular residue option due to its simplicity and higher zinc recovery. However, with increasing environmental concerns associated with Jarosite storage and disposal, alternatives are being investigated and adopted including pyrometallurgical treatment options for the residue, as discussed in **Appendix 2.**

Chapter 3: Jarosite Generation and Management Practices in India

3.1 Indian Scenario

Currently, zinc mining and primary production in India is being done only by M/s Hindustan Zinc Limited. Another unit M/s Binani Zinc Limited (now rechristened as Edayar Zinc Limited) had a smelter unit in Kerala which got closed in 2014 and is now under the custody of lender banks and it looks unlikely to restart operations.

HZL currently has 7 smelters in operation, namely Chanderiya hydro 1, Chanderiya hydro 2, Chanderiya pyro, Chanderiya Ausmelt, Dariba zinc, Dariba lead and Debari, all located in the state of Rajasthan. HZL had another zinc smelter, at Visakhapatnam in the state of Andhra Pradesh, now closed since 2012, which was also based on hydrometallurgical route and was generating Jarosite as an iron residue.

Chanderiya pyro is an ISF smelter which is designed to produce zinc as well as lead but it has now been customized to mostly produce lead. Chanderiya Ausmelt and Dariba lead are both lead smelters. All others (4 in number) are zinc smelters based on hydrometallurgical route and generating Jarosite as the iron residue.

The Binani smelter also had its zinc smelter based on hydrometallurgical route and, before its closure in 2014, was generating Jarosite as iron residue.

3.1.1 Manufacturing Process and Jarosite generation

The zinc manufacturing flow sheet adopted by Indian smelters broadly is the same as represented in Figure 2.1 with individual differences in respect of type and size of equipment used and the by-products produced (Pb-Ag residue, Cu cement, Cadmium, etc). Also varying within different smelters would be the process variables within the broader process scheme and exact steps to achieve the same final outcome. The Jarosite is precipitated using sodium sulphate at all the smelters now. Debari was earlier using ammonium sulphate but switched to sodium sulphate some years back. Edayar and Vizag smelters were generating ammonium Jarosite till their closure.

At the old smelters, viz., Debari, Vizag and Binani, the Jarosite – after generation and filtration – was being neutralized with hydrated lime slurry before disposal in slurry form in captive Jarosite ponds. In the new smelters, viz., Chanderiya and Dariba, the Jarosite stabilization process has been adopted right from inception whereby the Jarosite, after filtration, is mixed with lime (2-3%) and cement (10-15%) and then disposed off in an on-site storage yard. Binani smelter had adopted stabilization process in 2010 as an additional option while continuing to use Jarosite pond. A portion of the generated Jarosite was also being sent to a local TSDF for disposal.

Details of zinc production, Jarosite generation and disposal practices adopted at different Indian smelters are presented in **Table 5** below. Details in respect of Binani smelter were available only in bits due to inaccessibility of documents/records and company personnel.

Table 5: Jarosite disposal practices in Indian Zinc Smelters

<table>
<tr><th rowspan="3">S.No</th><th rowspan="3">Name of Smelter</th><th colspan="3">Jarosite Generation</th><th colspan="4">Jarosite Waste Management Practices</th></tr>
<tr><th rowspan="2">Jarosite generation started from (year)</th><th rowspan="2">Total Jarosite generated during life*, DMT (WMT)</th><th rowspan="2">Current Annual generation [$] MTPY@</th><th colspan="2">Slurry disposal</th><th rowspan="2">Stabilized as jarosite, disposal in lined area</th><th rowspan="2">Utilization</th></tr>
<tr><th>unlined pond</th><th>lined pond</th></tr>
<tr><td>1.</td><td>Dariba</td><td>2009</td><td>1800000 (3272000)</td><td>180000</td><td>N</td><td>N</td><td>Y</td><td>Nil</td></tr>
<tr><td>2.</td><td>Debari</td><td>1981</td><td>1500000 (2727000)</td><td>76000^{+}</td><td>Y</td><td>Y</td><td>N</td><td>Cement, 15715</td></tr>
<tr><td>3.</td><td>Chanderiya Hydro 1</td><td>2005</td><td rowspan="2">3500000 (6360000)</td><td rowspan="2">300000</td><td rowspan="2">N</td><td rowspan="2">N</td><td rowspan="2">Y</td><td rowspan="2">Stabilized(fixed) Jarosite: 173384 T (Road, etc); Jarosite: 8915 T (cement)</td></tr>
<tr><td>4.</td><td>Chanderiya Hydro 2</td><td>2007</td></tr>
<tr><td>4.</td><td>Binani/ Edayar (closed)</td><td>1981</td><td>500000 (900000)</td><td>NIL</td><td>Y</td><td>Y</td><td>Y</td><td>Nil</td></tr>
<tr><td>5.</td><td>Vizag (closed)</td><td>2002</td><td>318418[#] (579000)</td><td>NIL</td><td>N</td><td>Y</td><td>N</td><td>Nil</td></tr>
<tr><td></td><td>Total</td><td></td><td>~ 7.62mT (13.84mT)</td><td>556000</td><td></td><td></td><td></td><td></td></tr>
</table>

*Till 31 March 2019; [#]till plant closure in 2012; [@]Dry tonnage except Binani; [$]as per last consent/authorization granted; [+]not mentioned in Authorization

Source: HZL, EDL, KSPCB

3.2 Jarosite Management

Description of individual smelters with regards to Jarosite generation & treatment/ disposal methodology and current status follows.

3.2.1 Debari Zinc Smelter

The relevant details are mentioned in **Table 6** below:

Table 6: Debari Zinc Smelter, Hindustan Zinc Limited

Smelter started in year	1967
Jarosite started in year 1981	• Before 1981, NL residue was generated, treated in Waelz Kiln (2004 onwards) for recovery, with slag as final waste
Total Jarosite generated, DMT	• 820896 Metric Tons, dry basis (From 2003 to 2019-20).
Disposal methodology : Jarosite is disposed after lime treatment in all three 'ponds'. Height of Pond 3 raised twice in 2002.	• Ponds 1 and 2 unlined; • Fig 3, 4 and 5: details of pond 3; total area covered: 18 ha; height 14 m

		• Other HWs also disposed off into the ponds, viz, cobalt cake, cooler cake, anode mud, ETP sludge, etc.
Current status	Ponds 1&2 capped in 2011; Pond 3 not yet capped	• Barrier wall constructed d/s of ponds 1 and 2.
Utilisation of Jarosite	15964 tonnes sent to M/s JK Cement, Nimbahera	• Balance Jarosite being stockpiled.

The analysis results of metals in ground water, treated Jarosite & stabilized(fixed) Jarosite along with leachability analysis are given at **Table 7 to 9**.

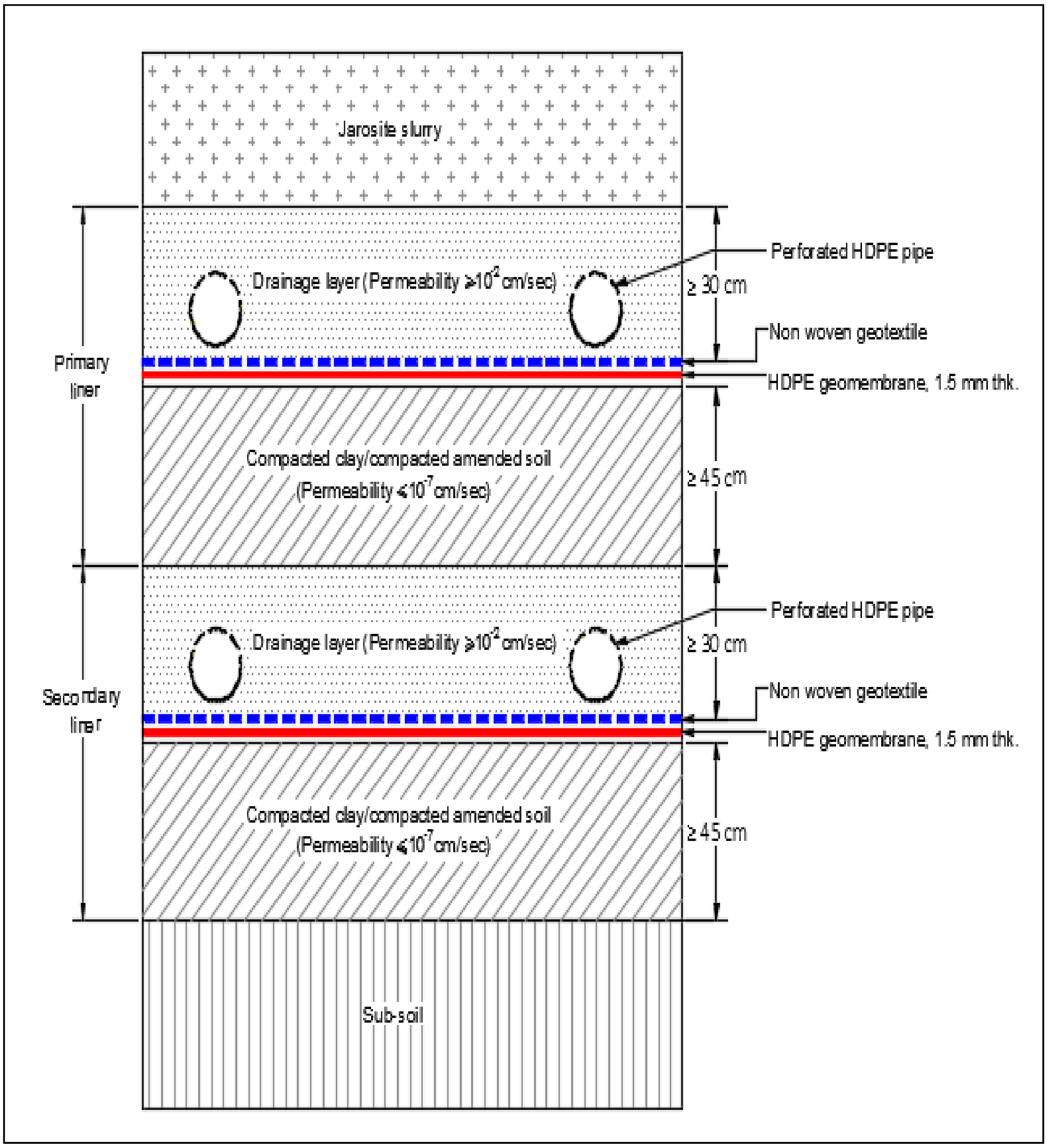

Figure 3: Cross Section of Liner System used at Jarosite Pond at Debari (The same liner system has also been used at Vizag and Binani/ Edayar smelters)

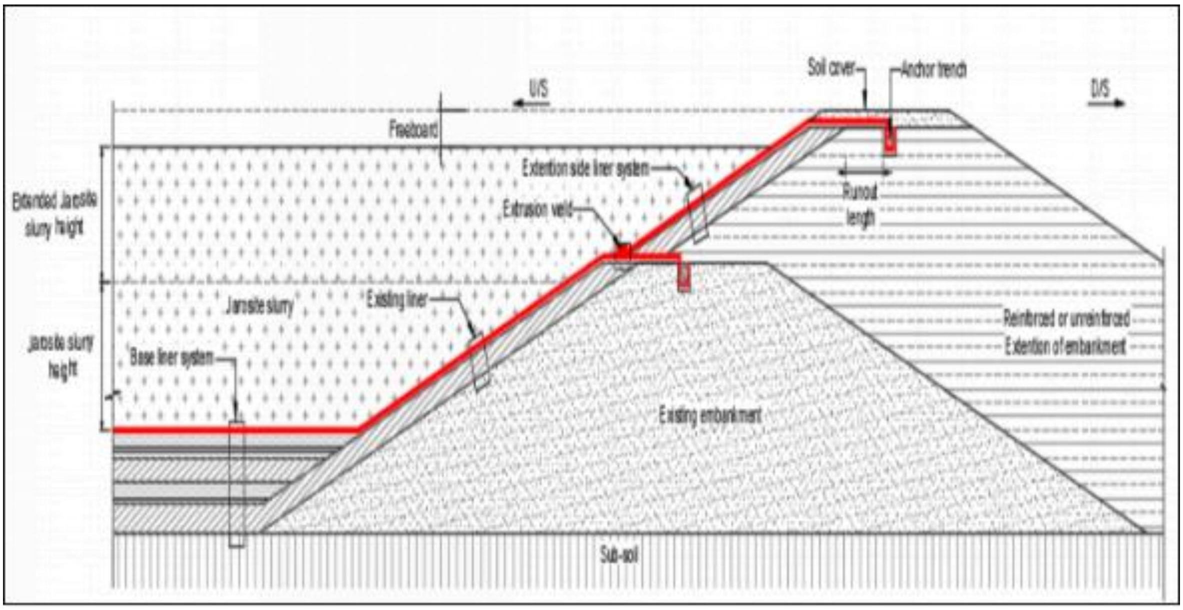

Figure 4: Cross section of Jarosite pond expansion in downstream side, Debari

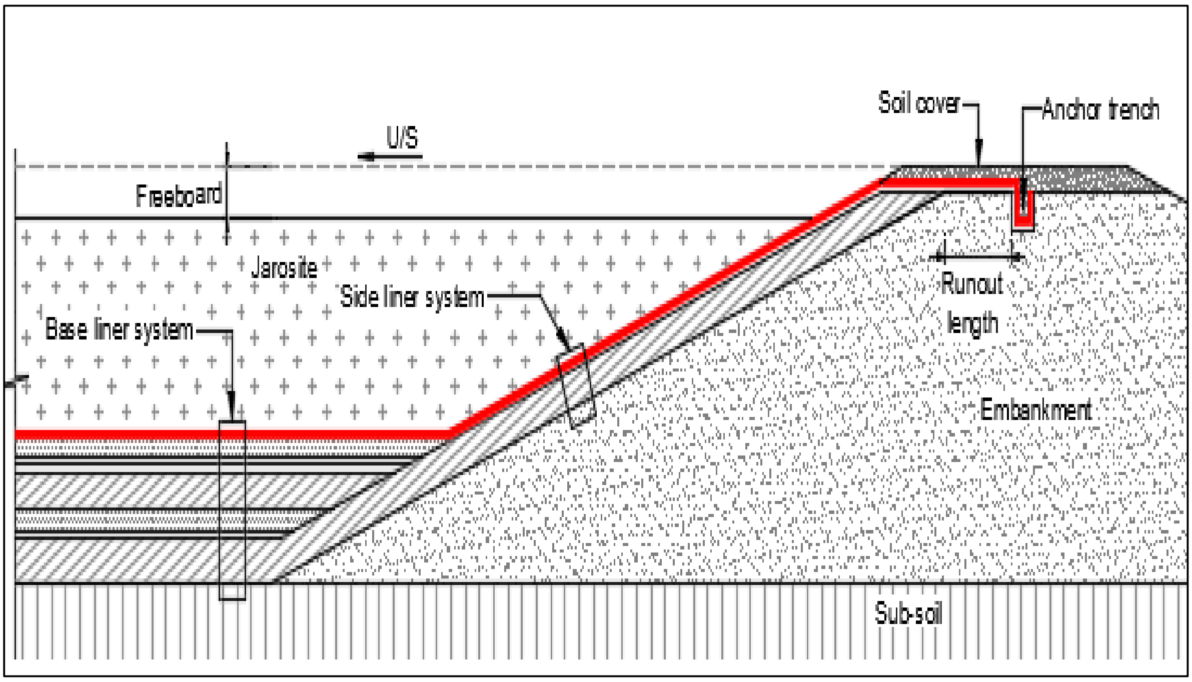

Figure 5: Typical cross section of Jarosite pond at Debari

Table 7: Piezometer Wells (Ground Water) analysis at Hindustan Zinc Limited, Debari Unit

Detection limit		0.49	0.42	0.35	0.56	0.35	0.67	0.43	0.54	0.31	0.59	0.2
S.No.	**Sampling Point**	**As (mg/l)**	**Cd (mg/l)**	**Co (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Ni (mg/l)**	**Pb (mg/l)**	**Zn (mg/l)**	**Hg (µg/l)**
1.	P 1	BDL	BDL	BDL	BDL	BDL	0.49	0.02	BDL	0.01	0.2	BDL
2.	P 4	BDL	BDL	BDL	BDL	BDL	0.62	0.02	BDL	BDL	0.16	4.62
3.	P 5	BDL	BDL	BDL	BDL	0.02	1.4	0.03	BDL	0.1	0.29	3.22
4.	P 7	BDL	BDL	BDL	0.01	BDL	0.48	0.02	BDL	0.03	0.16	3.42
5.	P 9	Dry Piezometer well										
6.	P 10	BDL	BDL	BDL	BDL	BDL	0.21	0.01	BDL	BDL	0.09	BDL
7.	Village	BDL	BDL	BDL	BDL	0.01	0.82	0.05	BDL	0.02	1.02	BDL

P1, P2, .. - Piezometer wells around the Disposal ponds. ; BDL: Below Detection Limit

Table 8: Metal analysis of treated/stabilized(fixed) Jarosite at Hindustan Zinc Limited, Debari Unit

S.No.	**Sampling Point**	**pH**	**Moisture (%)**	**Hg (mg/Kg)**	**Cd (mg/Kg)**	**Co (mg/Kg)**	**Cr (mg/Kg)**	**Cu (mg/Kg)**	**Fe (mg/Kg)**	**Mn (mg/Kg)**	**Ni (mg/Kg)**	**Pb (mg/Kg)**	**Zn (mg/Kg)**
1.	Jarosite Pond	6.59	33.14	23.12	351.90	BDL	98.30	1041.80	190492.60	895.80	4.70	36550.00	38894.90
2.	Filter Press	10.49	44.81	3.22	108.50	BDL	72.10	1033.80	200642.60	178.80	BDL	31750.00	23169.90
3.	HBF Jarosite	3.3	45.52	4.82	149.70	BDL	84.10	1198.80	226267.60	244.30	BDL	36575.00	28069.90

BDL: Below Detection Limit

Table 9: Leachability analysis of treated/stabilized(fixed) Jarosite at Hindustan Zinc Limited, Debari Unit

		TCLP						STLC				
S.No.	**Sampling Point**	**As (mg/l)**	**Cd (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Pb (mg/l)**	**Hg (mg/l)**	**Co (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Ni (mg/l)**	**Zn (mg/l)**
1.	Jarosite Pond	0.03	6.23	0.11	17.76	0.05	BDL	0.19	0.12	4.47	0.27	911.77
2.	Filter Press	0.01	2.70	BDL	3.80	2.70	128.64	BDL	0.20	1.33	BDL	7.38
3.	HBF Jarosite	0.03	5.86	0.04	7.44	0.15	BDL	0.05	0.34	9.87	0.08	1087.97

BDL: Below Detection Limit

Figure 6: Jarosite pond no. 3, Debari Zinc Smelter, HZL, Rajasthan

Figure 7: Filter Press at Debari Unit

Figure 8: Filtered Jarosite before dispatch to cement plant at Debari unit

Figure 9: Solar panels on top of the capped Jarosite ponds no. 1 and 2 at Debari

3.2.2 Binani/Edayar Zinc Smelter

The relevant details are mentioned in **Table 10** below.

Table 10: Zinc Smelter, Binani/Edayar Zinc Limited

Smelter commissioning year-1967		
Jarosite production starting year	1981	Before 1981, NL residue generated and dumped, treated in Waelz Kiln for recovery, with slag as final waste
Total Jarosite generated, WMT	Approx. 9 lakh MT	For last two years before closure: Jarosite produced: 55911.7 MT Sent to TSDF: 24465 MT For Stabilization : 31445 MT Stabilized Jarosite: produced: 35738 MT
Plant closing year	2014	Now Under banks' custody
Disposal methodology	Till 2009, disposal in 4 ponds (constructed in 1981, 1990, 1996, 2003) after lime treatment. After May 2009, Jaroisite stabilization(fixing**)** and sending to TSDF also introduced.	Ponds 1, 2 and 3: 20 acres, 2 layers LDPE, brick lining at bottom & sides; all 3 now capped (1991, 1997, 2004) with 1 m soil, HDPE, 0.5 m soil. Pond 4 (10 acres) Fig 10: 1.5 mm HDPE liner, Geosynthetic Clay Liner (GCL)and Leachate Clay Liner (LCS). JY (8 acres) Fig 11: single composite liner. Other HWs also disposed off with Jarosite, viz, Cobalt cake, cooler cake, anode mud, ETP sludge, etc.
Current status	Pond 04 not capped yet, has 2.5 m water & ~1.5 m free board.	Periyar river flows nearby, <500 m. Ponds are not maintened
Utilisation of Jarosite	Many studies/ trials done, no regular use. Details at **Table 31.**	Some quantities of lime treated Jarosite / stabilized Jarosite used to make tiles for in-house consumption

The analysis results of metals in ground water, lime treated Jarosite & stabilized Jarosite along with leachability analysis of the same are given at **Table 11 to 13**.

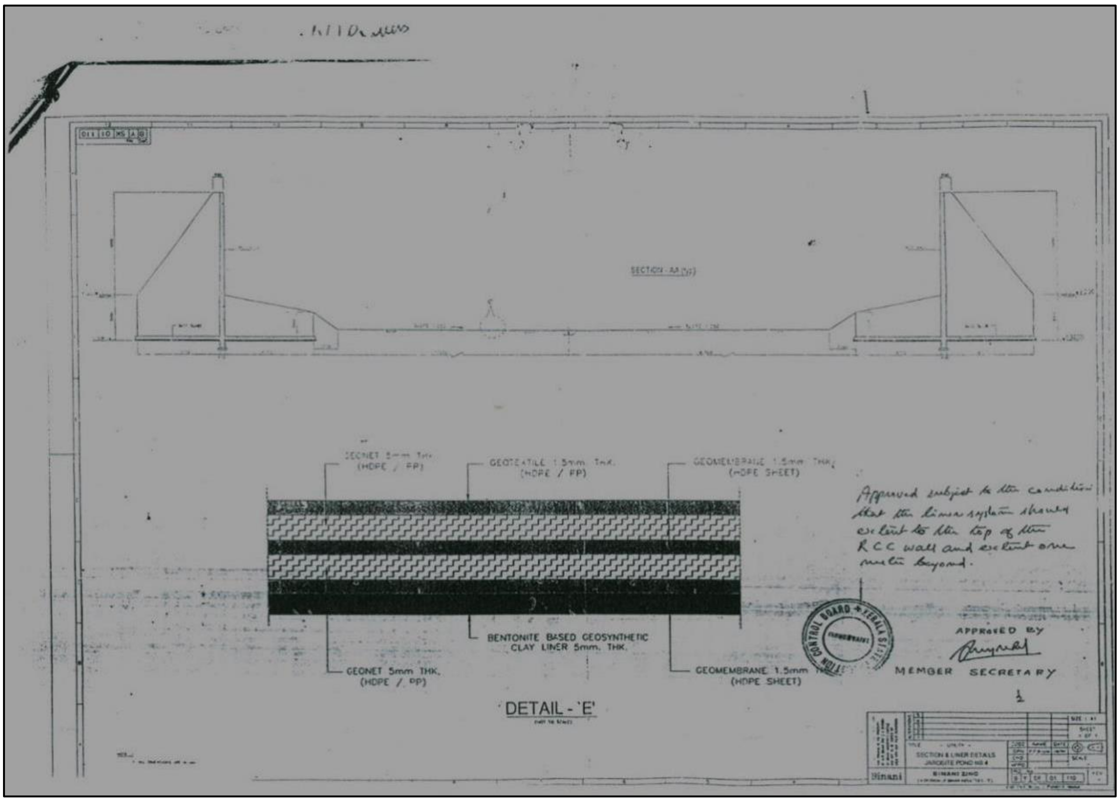

Figure 10: Details of Liner system of Jarosite Containment Yard at Edayar Zinc Limited

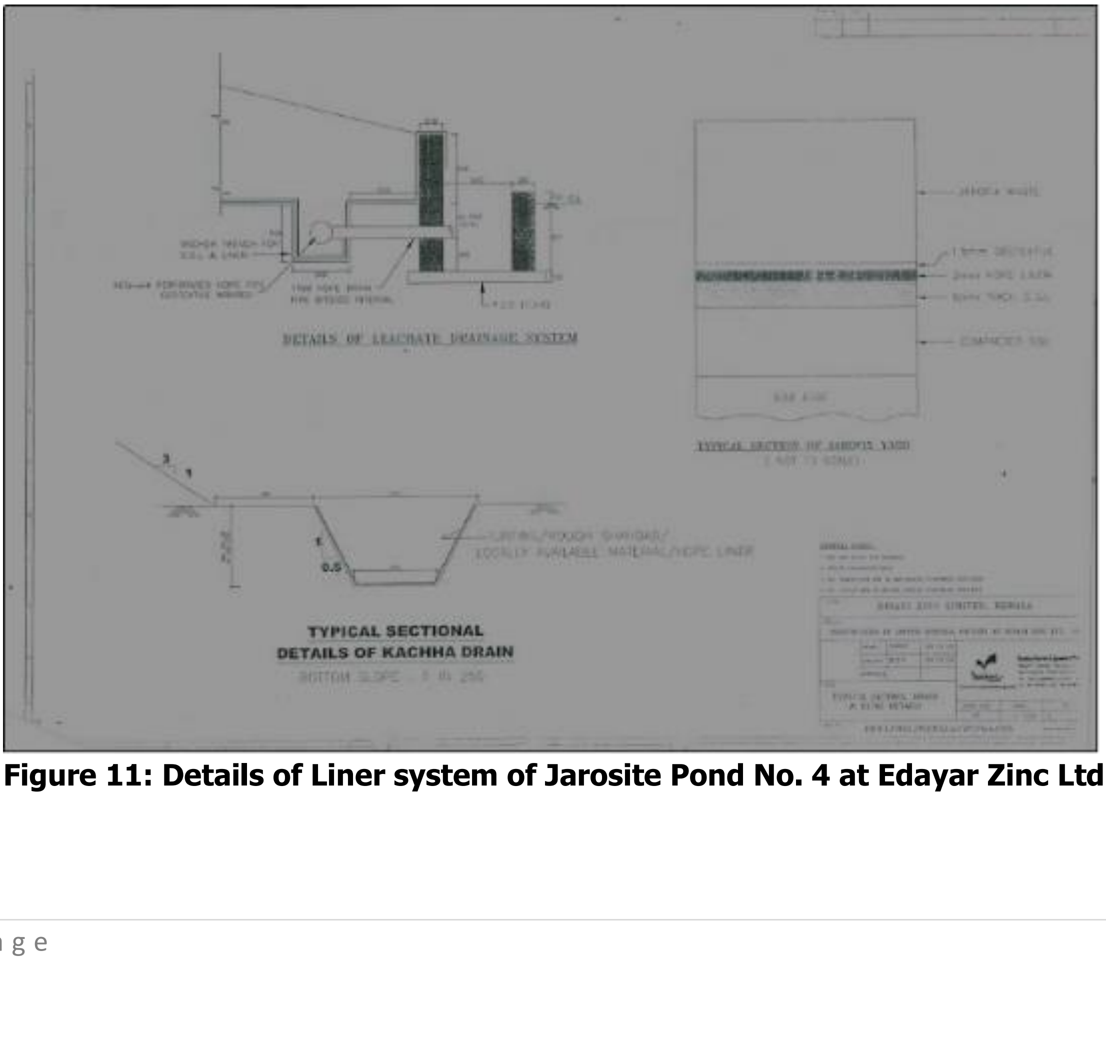

Figure 11: Details of Liner system of Jarosite Pond No. 4 at Edayar Zinc Ltd.

Table 11: Ground Water analysis at M/s Binani Zinc Limited

S.No.	Sampling Point	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Ni (mg/l)	Pb (mg/l)	Zn (mg/l)	Hg (mg/l)	Chloride as Cl	Calcium as Ca	Magnesium as Mg	Total Alkalinity as CaCO3	Fluoride	*NO3-NO3
1	Surface water near stabilization area	0.01	BDL	BDL	0.25	BDL	BDL	0.23	BDL	18	378	23	55	0.9	1.3
2	Water from Jarosite Pond	0.05	BDL	BDL	0.49	BDL	0.06	4.38	BDL	15	218	45	15	1.4	1
3	Water from U/s of Periyar River	BDL	BDL	BDL	0.92	BDL	0.01	0.71	BDL	14	8	23	15	BDL	1.7
4	Water from D/s of Periyar River	0.03	BDL	0.02	0.72	BDL	0.01	9.06	BDL	13	13	36	17	0.2	1.8

BDL: Below Detection Limit

Table 12: Analysis of lime treated Jarosite & stabilized Jarosite at M/s Binani Zinc Limited

S.No.	Sampling Point	Moist. %	pH (1:2.5)	Conductivity (µmho/cm) (1:2)	Org. Matter (%)	Ca (mg/100g)	Mg (mg/100g)	Exchangeable Na% (ESP)	CEC meq/100g	Fe (mg/Kg)	Pb (mg/Kg)	Zn (mg/Kg)
1	Jarosite-ALT	87.42	7.23	3800	1.98	1363	302	0.69	93.64	116689.6	21057.9	180993
2	Jarosite-Stabilized	27.75	7.76	2570	0.55	5242	146	0.08	274.52	153189.6	19447.9	24113

Table 13: Analysis of Jarosite & stabilized Jarosite at M/s Binani Zinc Limited

S.No.	Sampling Point	TCLP				STLC				
		Cd (mg/l)	Fe (mg/l)	Mn (mg/l)	Pb (mg/l)	Co (mg/l)	Cr (mg/l)	Cu (mg/l)	Ni (mg/l)	Zn (mg/l)
1	Jarosite-ALT	34.15	3.84	36.2	4.24	BDL	0.01	0.04	BDL	9.83

2	Jarosite-Stabilized	9.5	26.45	4.09	60.8	BDL	BDL	0.1	BDL	0.65

BDL: Below Detection Limit

Figure 12: Capped Jarosite ponds no. 1, 2 and 3 at Edayar Zinc Ltd.

Figure 13: Panoramic view of Jarosite pond no. 4 at Edayar Zinc Ltd, filled with water

Figure 14: Stabilized Jarosite yard at Edayar Zinc Ltd. showing HDPE lining and stock

Figure 15: Covered pathway for dumpers carrying stabilized Jarosite at EDL

3.2.3 Vizag Zinc Smelter

The relevant details are mentioned in **Table 14** below.

Table 14: Visakhapatnam Zinc Smelter, Hindustan Zinc Limited

<table>
<tr><td colspan="2">Smelter started in year</td><td colspan="2">1977</td></tr>
<tr><td>Jarosite started in year</td><td>2002</td><td colspan="2">Earlier NL residue treated in Waelz Kiln for recovery, with slag as final waste</td></tr>
<tr><td>Plant closed in</td><td>Feb 2012</td><td colspan="2">All plant and machinery with buildings dismantled except ETP and Jarosite ponds</td></tr>
<tr><td>Total Jarosite generated, DMT</td><td>3,18,418</td><td colspan="2">Wet tonnage approx. 5,78,000 T @ 45% moisture content</td></tr>
<tr><td>Disposal methodology</td><td>After lime treatment, disposal in 2 Jarosite ponds; area covered: 6 ha and 4 ha; height 10 m.</td><td>Fig 16 details of side liner and Fig 17 for bottom liner; Fig 18 for anchoring details</td><td>Other HWs disposed off into the two ponds, viz, Cobalt cake, cooler cake, anode mud, ETP sludge, etc. Some NL residue in pond 1 & plant dismantling waste (50773 T) in pond 2.</td></tr>
<tr><td>Current status</td><td>Pond no. 1 capped in 2011, pond no. 2 not capped yet</td><td>Plan for capping pond no. 2 during 2020-21; 4.317 cr escrow fund created for 30 years</td><td>Capped pond grass overgrown, no leachate; drains & embankments in bad condition Pond 2: no leachate except during rains; ETP alive for treatment of leachate generated before discharge</td></tr>
<tr><td>Utilisation of Jarosite</td><td colspan="3">NIL</td></tr>
</table>

The analysis results of metals in ground water, Jarosite & stabilized Jarosite along with leachability analysis of the same are given at **Table 15 to 17**.

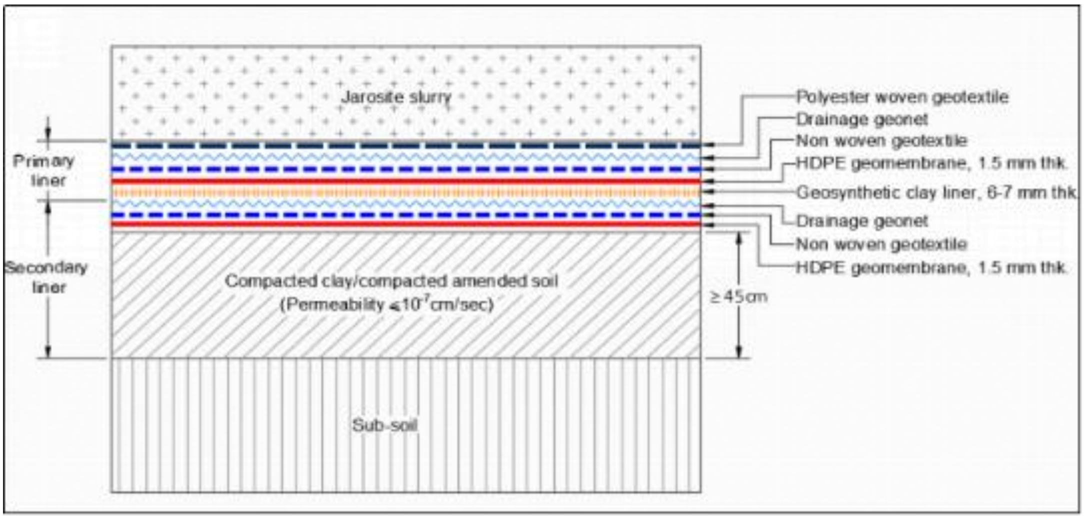

Figure 16: Typical cross section of side lining system of Vizag Jarosite pond

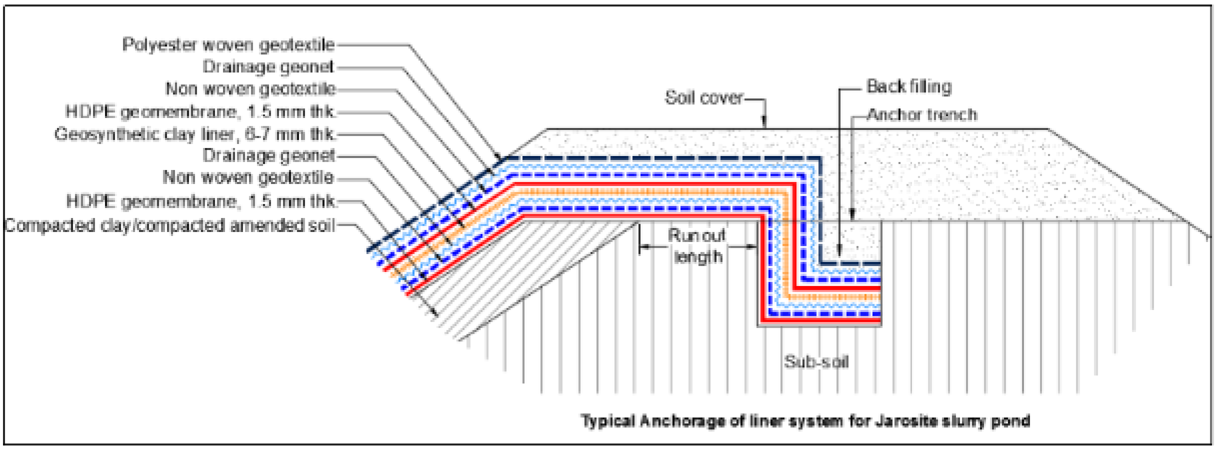

Figure 17: Typical anchoring of liner system for Vizag Jarosite pond

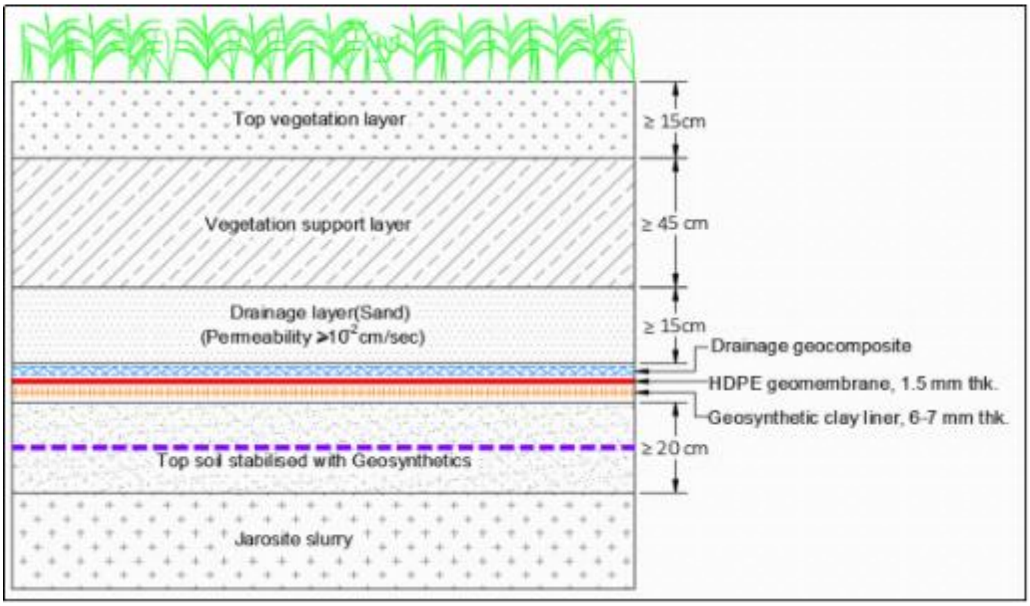

Figure 18: Typical cross section of lining system for closure and capping of Vizag Jarosite pond

Table 15: Ground Water analysis at M/s Binani Zinc Limited

S.No.	Sampling Point	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Ni (mg/l)	Pb (mg/l)	Zn (mg/l)	Hg (mg/l)	Chloride	Calcium as Ca	Magnesium as Mg	Total Alkalinity as $CaCO_3$	Fluoride	*NO_3-NO_3
1.	PW-6	0.02	BDL	0.03	3.44	BDL	0.41	1.72	BDL	80	124	5	375	1.6	37.9
2.	PW-11	BDL	BDL	BDL	1.08	BDL	0.06	0.53	BDL	72	91	25	337	1.6	52.1
3.	PW-03	0.01	BDL	BDL	1.71	BDL	0.11	1.22	BDL	76	68	38	333	1.2	40.5
4.	PW-9	0.01	BDL	BDL	2.12	BDL	0.12	1.92	BDL	78	106	44	349	1.6	49.6
5.	PW-8	0.01	BDL	BDL	1.43	BDL	0.1	0.78	BDL	78	59	45	327	1.4	41.5
6.	Surface Water Drain	0.26	BDL	BDL	1.72	BDL	0.14	7.02	1.52	133	196	58	729#	1.54	4.4
7.	ETP	21.9	0.02	1.23	8.22	0.26	3.09	837.2	1.77	108	876	349	3622#	2.42	3.5

P1, P2, .. - Piezometer wells around the Disposal ponds; BDL: Below Detection Limit; # Total Hardness

Table 16: Analysis of Jarosite & stabilized Jarosite at M/s Binani Zinc Limited

S.No.	Sampling Point	Moist. %	pH (1:2.5)	Conductivity (µmho/cm) (1:2)	Org. Matter (%)	Exchangeable Na (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	Exchangeable Na% (ESP)	CEC meq/100g	Fe (mg/kg)	Pb (mg/Kg)	Zn (mg/Kg)
1	Jarosite Pond	19.72	6.04	5330	0.32	16	3848	546	0.29	237.73	143700	15060	29900

Table 17: Analysis of Jarosite & stabilized Jarosite at M/s Binani Zinc Limited

S.No.	Sampling Point	TCLP				STLC				
		Cd (mg/l)	Fe (mg/l)	Mn (mg/l)	Pb (mg/l)	Co (mg/l)	Cr (mg/l)	Cu (mg/l)	Ni (mg/l)	Zn (mg/l)
1	Jarosite Pond	2.54	0.34	30.2	0.19	0.15	BDL	0.23	1.63	578

BDL: Below Detection Limit

3.2.4 Chanderiya hydro 1 and hydro 2 Zinc Smelters

The relevant details are mentioned in **Table 18** below.

Table 18: Hydro 1 and Hydro 2, Chanderiya Zinc Smelters, HZL

Smelters started in year	2005, 2007	Generation of stabilized Jarosite generation started from inception
Total Jarosite generated, DMT (till 31/01/2021)	4124107	Wet tonnage approx. 5979955 T @ 45% moisture
Disposal methodology	Jarosite stabilized with with lime (2 – 3%) and cement (10 – 15%), cured and disposed of in Jarosite yards	Fig 19 and 20 show typical cross sections of bottom liner system and anchoring details used for construction of Jarosite yards
Current status	2 yards completed and temporarily capped with HDPE sheets; 3rd yard in operation.	Hydro 2 under conversion to fumer option*. Instead of Jarosite, WAL residue will be fumed for metal recovery and slag generation. Fumer is expected to be operational by end of financial year June, 2022.
Utilization	5000 MT stabilized Jarosite used as embankment in a test patch of 300 m, utilization in flyover is in progress.	

*There is a significant loss of metals like zinc, lead, copper, silver and other minor metals in the waste due to generation of Jarosite. The most successful process for recovery of metals, without the formation of Jarosite, is the Zinc Fumer Plant. It not only deviates from the process of formation of Jarosite, instead, recovers the metals from the waste. While treating waste, the Zinc Fumer Plant will also produce a large quantity of slag that could be fully utilized by the cement industry. The major recovery from the Zinc Fumer Plant would be in lead and silver.

The analysis results of metals in ground water, Jarosite & stabilized Jarosite along with leachability analysis of the same are given at **Table 19 to 21**.

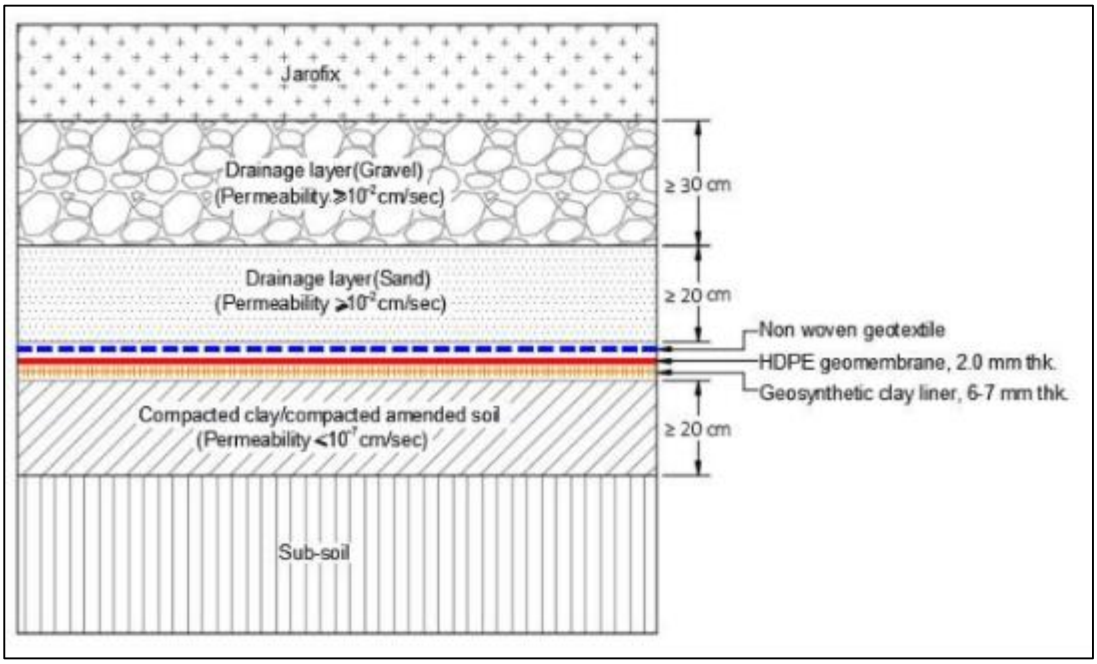

Figure 19: Typical cross section of liner system for Jarisite yard construction

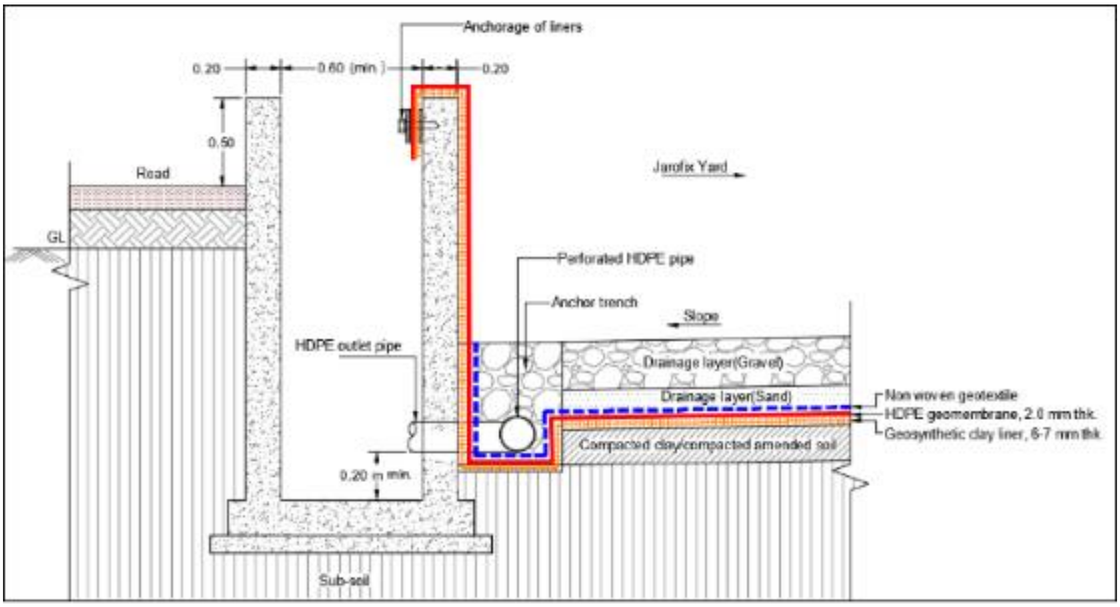

Figure 20: Typical cross section of liner anchoring system for Jarisite yard

Table 19: Piezometer Wells (Ground Water) analysis at Hindustan Zinc Limited, Chanderiya Unit

S.No.	Detection limit		0.49	0.42	0.35	0.56	0.35	0.67	0.43	0.54	0.31	0.59	0.2
	Sampling Point		**As (mg/l)**	**Cd (mg/l)**	**Co (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Ni (mg/l)**	**Pb (mg/l)**	**Zn (mg/l)**	**Hg (µg/l)**
1.	Around Dump Yard 3	P 15	BDL	BDL	BDL	BDL	0.01	0.52	0.05	BDL	0.06	0.21	BDL
2.		P 16	BDL	BDL	BDL	BDL	BDL	0.89	0.08	BDL	0.12	0.25	BDL
3.		P 18	BDL	BDL	BDL	BDL	BDL	1.22	0.09	BDL	0.07	0.25	BDL
4.	Around Dump Yard 2	P 7	BDL	BDL	BDL	BDL	0.02	1.49	0.1	BDL	0.23	0.33	BDL
5.		P 9	BDL	BDL	BDL	BDL	0.01	1.85	0.09	BDL	0.17	0.37	BDL
6.		P 10	BDL	BDL	BDL	BDL	0.01	0.48	0.06	BDL	0.06	0.28	BDL
7.		P 11	BDL	BDL	BDL	BDL	0.01	0.43	0.04	BDL	0.07	0.27	BDL
8.	Around Dump Yard 1	P 3	BDL	BDL	BDL	BDL	0.02	5.7	1.31	BDL	0.5	1.04	BDL
9.		P 4	BDL	0.02	BDL	BDL	0.01	7.11	0.87	BDL	0.37	1.09	BDL
10.		P 5	BDL	BDL	BDL	BDL	0.02	3.69	1.41	BDL	0.65	1.05	BDL

P1, P2, .. - Piezometer wells around the Disposal ponds. ; BDL: Below Detection Limit

Table 20: Metal analysis of Jarosite & stabilized Jarosite at Hindustan Zinc Limited, Chanderiya Unit

S.No.	Sampling Point	pH	Moisture (%)	Hg (mg/Kg)	Cd (mg/Kg)	Co (mg/Kg)	Cr (mg/Kg)	Cu (mg/Kg)	Fe (mg/Kg)	Mn (mg/Kg)	Ni (mg/Kg)	Pb (mg/Kg)	Zn (mg/Kg)
1.	Pond 1	9.35	43.95	2.01	176.40	BDL	64.20	979.20	168592.60	473.90	2.30	21225.00	17944.90
2.	Pond 2	9.24	37.84	3.82	167.00	BDL	62.10	979.10	178742.60	850.90	2.70	29725.00	21044.90
3.	Pond 3 (Active)	8.85	22.82	3.42	121.90	BDL	52.90	862.50	175542.60	1001.10	3.00	28200.00	27919.90
4.	HBF Jarosite	2.64	45.32	1.41	129.30	BDL	84.50	1067.80	227417.60	254.10	BDL	33675.00	18569.90
5.	stabilized Jarosite fresh	11.31	52.83	1.21	144.50	BDL	69.90	858.30	175867.60	535.20	3.00	21600.00	20769.90

6.	stabilized Jarosite after curing	10.5	48.95	1.21	111.80	BDL	53.70	688.60	167692.60	340.40	1.60	26700.00	14844.90

BDL: Below Detection Limit

Table 21: Leachability analysis of stabilized Jarosite fresh at Hindustan Zinc Limited, Chanderiya Unit

S.No.	**Sampling Point**	**TCLP**						**STLC**				
		As (mg/l)	**Cd (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Pb (mg/l)**	**Hg (mg/l)**	**Co (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Ni (mg/l)**	**Zn (mg/l)**
1	Pond 1	0.02	6.17	0.23	13.63	7.64	BDL	BDL	0.06	0.32	BDL	7.91
2	Pond 2	0.02	5.07	0.04	9.37	17.42	BDL	BDL	0.07	4.76	0.02	11.02
3	Pond 3	0.05	0.04	BDL	0.19	0.05	BDL	0.02	0.04	3.05	0.02	12.00
4	HBF Jarosite	0.02	6.84	0.02	19.15	8.41	BDL	0.06	0.26	12.32	0.07	955.97
5	stabilized Jarosite fresh	0.02	0.21	BDL	6.34	0.13	12.06	BDL	0.07	0.07	BDL	0.11
6	stabilized Jarosite fresh	0.01	2.01	BDL	10.75	0.75	14.07	BDL	0.06	0.02	BDL	1.10

BDL: Below Detection Limit

Figure 21: Lime Feeder System at Chanderiya hydro smelter

Figure 22: Horizontal Belt Filter

Figure 23: Cement mixer for Stabilized Jarosite at Chanderiya hydro smelter

Figure 24: Stabilized Jarosite in curing yard after cement mixing at Chanderiya hydro smelter

Figure 25: Plantation (carried out by TERI) on Old Stabilized Jarosite Pond 1 at Chanderiya unit

Figure 26: Plantation (carried out by TERI) on a section of Old Stabilized Jarosite pond 2 at Chanderiya unit

Figure 27: Slag spread over the HDPE sheet to hold it from blowing with the wind

Figure 28: 300 m test patch of road constructed using stabilized Jarosite

3.2.5 Dariba hydro Zinc Smelter

The relevant details are mentioned in **Table 22** below.

Table 22: Dariba Zinc Smelter, Hindustan Zinc Limited

Smelter started in year	2009	stabilized Jarosite option started from inception
Total Jarosite generated, DMT	1786833 T	Wet tonnage approx. 2590908 T @ 45% moisture
Disposal methodology	Jarosite mixed with lime (2–3%) & cement (10–15%), cured & disposed off in stabilized Jarosite yards	Figure 29 show typical cross sections of bottom liner system & anchoring details used for construction of stabilized Jarosite yards
Current status	Both phases of 1st yard are exhausted and temporarily capped with HDPE sheets; Phase 1 of 2nd yard has been exhausted and being covered with HDPE whereas Phase 2 is operational.	
Utilization of Jarosite	NIL	

The analysis results of metals in ground water, Jarosite & stabilized Jarosite along with leachability analysis of treated Jarosite and stabilized Jarosite are given at **Table 23 to 25**.

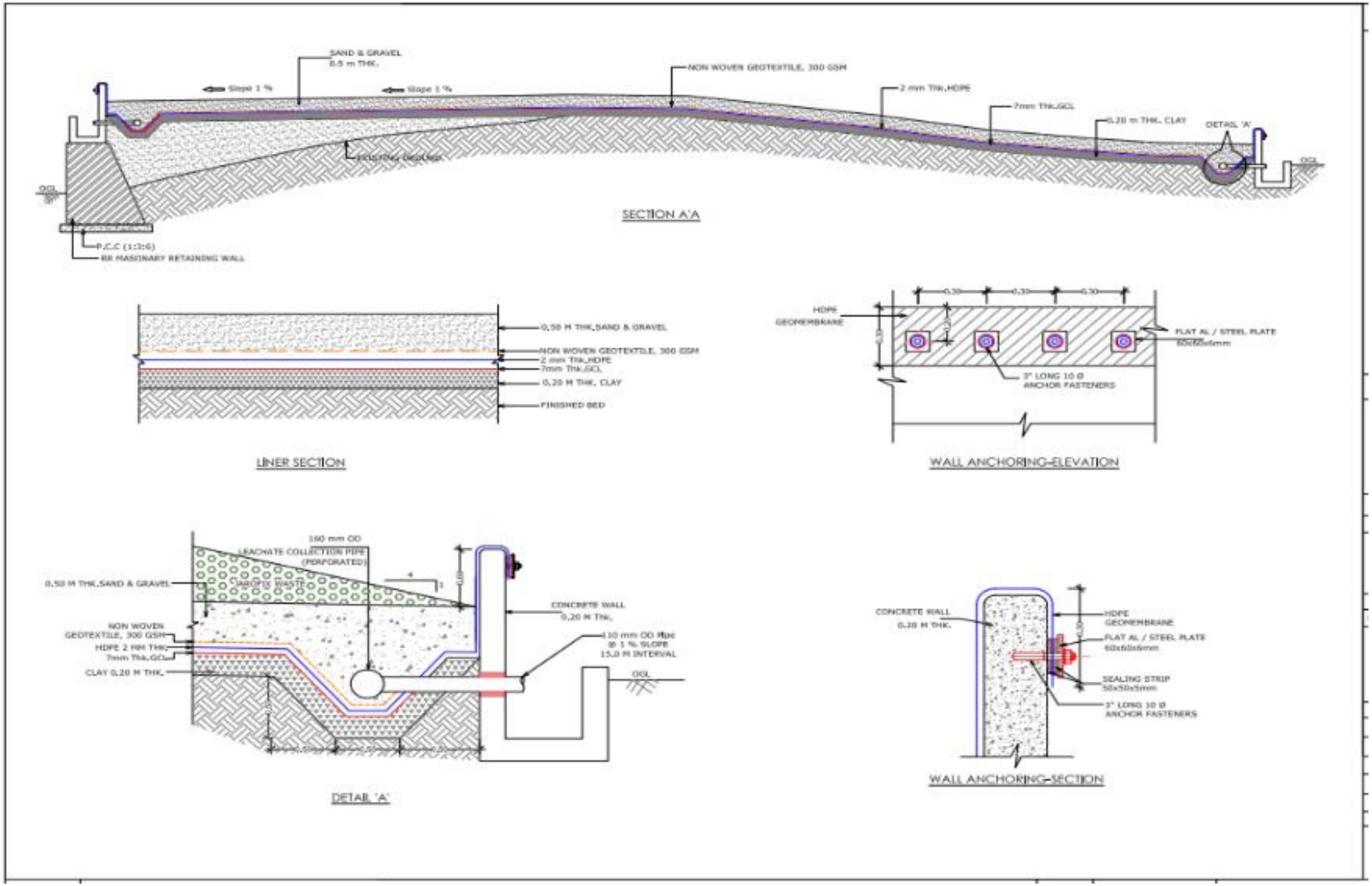

Figure 29: Typical cross section of stabilized Jarosite yard

Table 23: Piezometer Wells (Ground Water) analysis at Hindustan Zinc Limited, Dariba Unit

Detection limit		0.49	0.42	0.35	0.56	0.35	0.67	0.43	0.54	0.31	0.59	0.2
S.No.	**Sampling Point**	**As (mg/l)**	**Cd (mg/l)**	**Co (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Fe (mg/l)**	**Mn (mg/l)**	**Ni (mg/l)**	**Pb (mg/l)**	**Zn (mg/l)**	**Hg (µg/l)**
1.	P 3	BDL	BDL	BDL	BDL	BDL	0.12	0.04	BDL	BDL	BDL	BDL
2.	D/s Village	BDL	BDL	BDL	BDL	0.01	0.13	BDL	BDL	BDL	0.07	BDL
3.	P 1	Dry Piezometer well										
4.	P 2	Dry Piezometer well										

P1, P2, .. - Piezometer wells around the Disposal ponds. ; BDL: Below Detection Limit

Table 24: Metal analysis of stabilized Jarosite at Hindustan Zinc Limited, Dariba Unit

S.No.	**Sampling Point**	**pH**	**Moisture (%)**	**Hg (mg/Kg)**	**Cd (mg/Kg)**	**Co (mg/Kg)**	**Cr (mg/Kg)**	**Cu (mg/Kg)**	**Fe (mg/Kg)**	**Mn (mg/Kg)**	**Ni (mg/Kg)**	**Pb (mg/Kg)**	**Z (mg**
1.	Old Pond 2	8.81	17.11	5.03	202.70	BDL	55.60	973.50	169442.60	695.80	3.00	26775.00	208
2.	Active Pond	9.88	40.27	60.30	253.50	BDL	66.10	912.90	159242.60	669.00	2.80	26300.00	173
3.	Old Pond 1	9.09	38.87	4.42	337.20	BDL	54.50	959.90	179067.60	696.90	3.30	25050.00	211
4.	HBF Jarosite	4.02	42.04	1.61	258.30	BDL	71.00	981.30	202292.60	216.60	BDL	25250.00	128
5.	stabilized Jarosite - fresh	9.47	40.19	3.42	262.30	BDL	70.10	864.40	166292.60	363.60	1.70	23325.00	169

BDL: Below Detection Limit

Table 25: Leachability analysis of Jarosite/stabilized-Jarosite at Hindustan Zinc Limited, Dariba Unit

S.No.	Sampling Point	pH	Moisture (%)	Hg (mg/Kg)	Cd (mg/Kg)	Co (mg/Kg)	Cr (mg/Kg)	Cu (mg/Kg)	Fe (mg/Kg)	Mn (mg/Kg)	Ni (mg/Kg)	Pb (mg/Kg)	Zn (mg/Kg)
1.	Old Pond 2	8.81	17.11	5.03	202.70	BDL	55.60	973.50	169442.60	695.80	3.00	26775.00	20844.90
2.	Active Pond	9.88	40.27	60.30	253.50	BDL	66.10	912.90	159242.60	669.00	2.80	26300.00	17394.90
3.	Old Pond 1	9.09	38.87	4.42	337.20	BDL	54.50	959.90	179067.60	696.90	3.30	25050.00	21144.90
4.	HBF Jarosite	4.02	42.04	1.61	258.30	BDL	71.00	981.30	202292.60	216.60	BDL	25250.00	12894.90
5.	stabilized Jarosite fresh	9.47	40.19	3.42	262.30	BDL	70.10	864.40	166292.60	363.60	1.70	23325.00	16969.90

BDL: Below Detection Limit

Figure 30: Leachate Pond at Dariba unit, post monsoon (next to old dumping pond)

Figure 31: Old stabilized Jarosite Pond at Dariba (exhausted and covered with HDPE)

Figure 32: Old stabilized Jarosite Pond at Dariba (Phase 1 and Phase 2 exhausted and covered with HDPE)

Figure 33: Active Pond at Dariba (Phase 1 exhausted and covered with HDPE; Phase 2 is operational)

Chapter 4: Characteristics of Jarosite

4.1 Physio-chemical characteristics of Jarosite

Jarosite is a yellow colored material with chemical formula: $Z(Fe_3SO_4)_2(OH)_6$ (where Z represents Na^+, K^+ or NH_4^+). The pH of Jarosite is acidic (2–3). The mineral phase in Jarosite, iron sulphate hydroxide, is hydrophobic in nature and insoluble. However, the other phase, iron sulphate hydrate, is hydrophilic and solubilizes easily. The Physio-chemical characteristics of Jarosite are mentioned in **Table 26** below.

Table 26: Physio-chemical characteristics of Jarosite

Characteristics	Unit	Value[8, 9]	Value[11]	Value[12]	Value[1Binani] KEIL
Specific Gravity	g/cm^3	2.88 – 3.0	NA	NA	NA
Bulk Density	g/cm^3	0.984	0.81	0.84	NA
Porosity	%	66.47 – 67.66	NA	NA	NA
Specific Surface Area	Cm^2/g	10463.52 - 10524.96	NA	NA	NA
Particle Size:			Powder	NA	NA
Sand	%	4.18			
Silt	%	63.47			
Clay	%	32.35			
Texture		Silty clay, loam			
D_{50}	µm	3.91+-0.03			
Electrical Conductivity	dS/m	13.260 – 14.090	NA	NA	NA
Moisture content	%	45 – 50	NA	NA	65.06
Calorific Value	Cal/g	NA	358.6	<50	497.2
Flash Point	^{0}C	NA	> 85	>80	NA
PFLT		NA	Pass	Pass	Fail

It can be seen that Jarosite is constituted of very fine particles with a very high porosity. The moisture content of the Jarosite is also very high. The Jarosite is known as a thixotropic material, i.e., very viscous and sticky material. Thus, it is difficult to handle and transport.

Table 27: Typical Oxide constituents of Jarosite, %

Constituent	Content[9], range	Value[11]	Value[12]	Value[1Binani] KEIL
pH	NA	6.0	6.73	2.49
LOI	14.39 – 15.92	9.5	8.92	NA
CaO	4.26 – 4.79	NA	NA	NA
SiO_2	4.74 – 5.52	NA	NA	NA
AL_2O_3	4.04 – 5.48	NA	NA	NA
Fe_2O_3	31.74 – 34.58	NA	NA	NA
MgO	0.11 – 0.13	NA	NA	NA
Na_2O	0.21 – 0.29	NA	NA	NA
K_20	0.21 – 0.29	NA	NA	NA

Table 28: Composition of Jarosite, %

Constituent	Content[9] (%)	Content[11] (%)	Content[12] (%)
pH	NA	6.0	6.73
Zn	2.5 – 3.5	NA	3.7
Fe	25 – 28	NA	13.1
Pb	3.5 – 4.5	NA	1.13
Cd	0.01 – 0.03	NA	0.015
Mn	0.05 – 0.25	NA	0.03
SO_3/SO_4	31.8 – 34.35	5.97	0.3
Cr(T)	NA	NA	0.043
Cu	NA	NA	0.06
Ni, ppm	NA	NA	31.9
Chlorides, as Cl	NA	5.52	0.58

The characteristics of Jarosite can vary widely based on the composition of concentrates used for zinc extraction (will primarily affect the chemical composition), operating parameters during zinc extraction (will affect the physio-chemical properties and filterability of Jarosite) and filtration efficiency (determines the soluble metal content, pH and moisture content). In view of the pH of the Jarosite samples as per **Tables 27 & 28** above, it is evident that the HZL samples were analyzed for samples of Jarosite after lime neutralization, so also for leachability analysis as per **Table 29** below.

Table 29: Leachability of Jarosite, mg/l

Constituent	Value[11]	Value[12]	Value[13]	Value[14]	Value[15]	Value[16]	Value[29] (EDL)	Threshold Sch II
pH	6.0	6.73	NA	NA	NA	NA	2.49	4-12
PFLT	Pass	Pass	NA	NA	NA	NA	Failed	Pass
Zn	301.2	144	25.58	34.01	26.85	36.21	501.5	250
Fe	1.3	10.9	1.91	0.09	2.3	1.2	NA	NS
Pb	0.9	1.2	1.93	0.35	2.03	0.45	9.24	5.0
Cd	5.0	1.2	0.92	0.70	0.94	0.73	19.96	1.0
Mn	10	6.5	3.96	9.05	3.98	9.12	NA	10.0
As	NA	NA	BDL	BDL	BDL	BDL	NA	5.0
Cr(T)/+6	BDL	0.5	BDL	BDL	BDL	BDL	0.13	5.0
Cu	1.6	0.2	BDL	0.09	BDL	0.12	12.15	25.0
Ni	0.2	0.11	0.07	0.11	0.09	0.14	0.35	20.0
Hg	NA	NA	BDL	BDL	BDL	BDL	NA	0.2
Co	0.1	0.17	0.03	0.05	0.07	0.09	NA	80.0

Constituent	Value[11]	Value[12]	Value[13]	Value[14]	Value[15]	Value[16]	Value[29] (EDL)	Threshold Sch II
Nitrate	NA	22.52	55.5	74.5	56.7	75.6	NA	1000
Tl	NA	NA	BDL	BDL	BDL	BDL	NA	7.0
Ammonia	NA	NA	15.4	BDL	16.1	12.4	NA	NS
Sulphides	NA	NA	1.2	1.4	1.6	1.7	NA	5.0
Fluorides	NA	NA	2.1	0.86	2.4	0.89	NA	180

(Source: HZL, EZL)

The typical leachability data of stabilized Jarosite is also summarized in **Table 30** below.

Table 30: Leachability of stabilized Jarosite , mg/l

Constituent	Value, Dariba	Value, Hydro 1	Value, Hydro 2	Value[1Binani] KEIL	Threshold, Sch II
Zn	14	1.064	1.064	0.05	250
Fe	1.10	NA	NA	NA	NS
Pb	1.59	0.032	0.032	BDL	5.0
Cd	0.82	0.027	0.027	BDL	1.0
Mn	1.25	NA	NA	NA	10.0
As	NA	NA	NA	NA	5.0
Cr(T)/+6	0.83	0.021	0.021	0.13	5.0
Cu	0.17	NA	NA	0.01	25.0
Ni	0.18	0.028	0.028	BDL	20.0
Hg	NA	NA	NA	NA	0.2
Co	0.42	NA	NA	NA	80.0
Nitrate	NA	NA	NA	NA	1000
Tl	NA	NA	NA	NA	7.0
Ammonia	NA	NA	NA	NA	NS
Sulphides	NA	NA	NA	NA	5.0
Fluorides	NA	NA	NA	NA	180
pH	9.68	10.47	10.28	11.0	
PFLT				Passed	Pass

(Source: HZL, EZL)

Broadly, Jarosite consists of practically all the iron and silica from the concentrate, along with sulphates and residual/unrecovered metals and impurities, viz., zinc, lead, cadmium, manganese, arsenic, mercury, cobalt, copper, nickel, thallium, etc. Jarosite, as generated, is highly acidic with high moisture content (45 – 50%). The material is extremely fine and is thixotropic, i.e., very viscous and sticky. Its bulk density is quite low (<1).

The traditional treatment for Jarosite before its disposal was neutralization with hydrated lime in slurry form, taking the pH to > 9. The purpose of lime neutralization was to neutralize the acidity and precipitate soluble part of zinc and other metals and Sulphate in the form of gypsum and raise the pH to alkaline. As can be seen from EDL results in Table 4.4, the Jarosite as generated has low pH, high leachable metals, viz, zinc, lead and cadmium, and fails the PFLT test. Lime treated Jarosite (HZL samples in Table 4.4) still has significant leachability and does not comply with the standards for direct landfilling.

From the leachability and disposal perspective, stabilized(fixed) Jarosite appears to be more successful as reflected in the TCLP values. Practically, after generation, Jarosite is well washed on the belt filters – to maximize recovery of soluble zinc and other metals and also to maximize the pH – before mixing hydrated lime (2-3% by weight) and OPC (10-15% by weight). The stabilized Jarosite so formed is left in storage bays within the plant premises for few hours to allow curing process to begin, after which it is transported in dumpers to the Jarosite disposal yards and systematically dumped there in lined landfill. The stabilized Jarosite continues to get 'cured' for several months, improving its physical as well as chemical properties to transform it into an environmentally stable material. Although it continues to retain significant moisture content, stabilized(fixed) Jarosite develops good compressive strength and low permeability.

Based on the understanding of its characteristics, the following are the main concerns with respect to management of Jarosite:

i) Highly acidic pH of the Jarosite as generated.
ii) High concentration of zinc (in the range of 2.7 -3.5 %) and lead (in the range of 3 - 5 %) and presence of toxic metals like cadmium, arsenic and mercury which may leach and contaminate the groundwater, if not stored and handled properly.
iii) High moisture content and very fine particles, low bulk density and thixotropic nature which make its handling and transport difficult and occupy large areas due to low bulk density.
iv) Lime neutralization reduces the leachability but doesn't make it safe for direct landfilling.
v) Stabilized(fixed) Jarosite after solidification/stabilization with lime and cement, has much superior physical as well as leaching characteristics.

4.2 Environmental impacts associated with Jarosite disposal

The environmental concerns associated with Jarosite ponds include ground and surface water pollution if located nearby. Main vectors for their transport into the environment are: leaching into surface and ground water, wind and water erosion, infiltration, and airborne emissions of dried material. Fine particles of Jarosite can be picked up and transported by wind and vehicular traffic into adjacent areas. Dust particles containing metals is a concern for operational and non-operational ponds.

The risks associated with Jarosite ponds are: permanent locking up of land, risks of failure of liners and/or embankments; risks of water accumulation in the ponds especially during the operational period as well as during the pre-closure period. For the older Jarosite ponds, the risks are: leachate seeping and contaminating the ground water, rains continuing to contribute to leachate generation including possible failure of embankments, especially in high rainfall areas, etc.

In case of stabilized(fixed) Jarosite, the environmental risks are significantly reduced on account of reduced leachability and hydraulic conductivity of the material, better strength and reduced potential for wind erosion. However, the locking up of land, even if reduced, and associated long-term risks still exist.

Chapter 5: Disposal and Utilisation of Jarosite

5.1 Introduction:

The total quantum of Jarosite, including stabilized-jarosite, across all smelters was more than 7 million tonnes (dry basis) and more than 12 million tonnes (wet tonnage) at the end of FY 18 – 19. Current annual generation is about 1 million tonnes per annum and is expected to increase owing to demand.

Disposal of Jarosite has evolved over the years from disposal as a slurry into unlined ponds, to disposal of lime-neutralized slurry in lined ponds, to disposal as stabilized (fixed) Jarosite. Approximately 8 lakh tonnes of Jarosite is available at the closed sites of Binani/Edayar and Vizag covering land area of 55 acres.

In view of the shortage of land available within existing smelter premises and the environmental risks of permanent storage of treated/stabilized Jarosite, efforts needs to be taken to utilize these wastes for different purposes. **Table 31** provides a summary of efforts made for utilization of lime-treated or stabilized(fixed) Jarosite .

Table 31: Studies on possible for utilization of untreated / treated / stabilized(fixed) Jarosite

S.No.	Agency	Purpose	Year	Conclusion / Possible options for utilization	Reference
1.	NCCBM	Study on use of Debari Jarosite in cement	2009	Up to 1.5% Jarosite as raw mix component (mineralizer) reduces clinkerisation temperature by up to 50°C. As set controller, up to 3% (out of total 5%) gypsum can be replaced with Jarosite.	9
2.	NCCBM	Study on use of Chanderiya Jarosite in cement	2014	Improved burnability (reduced clinkerisation temperatures by up to 50°C) without affecting strength. Negligible leaching for 24 months as per ASTMD 5233.	17
3.	BIS	Use of Jarosite in cement	2014, 2015	Clarification regarding use of Jarosite with clinker in cement mfg; Can use Jarosite not more than 1% during grinding stage	18, 18A
4.	NCCBM	Study use of Jarosite in cement	-	Replacement of 20% gypsum by Jarosite in OPC & 40% in PPC found optimum with negligible leaching	19
5.	RSPCB	Trial run of Debari Jarosite in cement kiln	2016	Permission for trial run of Jarosite for co-processing in JK Cement, Aditya Cement, ACC Lakheri	20
6.	RSPCB	Authorization for use of Jarosite in cement mill	2017	Permission for use of Jarosite in cement mill in Aditya Cement, 25000 TPY	21

S.No.	Agency	Purpose	Year	Conclusion / Possible options for utilization	Reference
7.	RSPCB	Authorization for use of Jarosite in cement mill	2018	Permission to use Jarosite in cement mill (JK Cement), 25000 TPY	22
8.	CIMFR	Study on use of Jarosite to replace OPC in paste fill	-	Jarosite can be used to replace OPC up to 12 – 13% for curing period of 28 days	23
9.	CEG, IISc	Study use of stabilized(fixed) jarosite for tailing dam material	2018	Suitable as embankment material if dried, used in downstream slope and used in sandwich form	24, 25
10.	IRC	Accreditation of stabilized(fixed) jarosite for road construction	2010, 2018	Accreditation and its Renewal for stabilized(fixed) jarosite as road embankment or sub-grade material, by itself or 50-75% mix with soil	26, 26A
11.	CRRI	Feasibility of using stabilized(fixed) jarosite in roads	2010	stabilized(fixed) jarosite is recommended for construction of embankment & construction of test sections of limited length.	27
12.	RSRDC, RSPCB	Test patch construction	2011	Construction of 300 m test patch on SH 9; performance evaluation of engg (CRRI) and environmental aspects (NEERI)	-
13.	NCCBM BZL/EZL	Study/trial for use of Jarosite in cement	NA	NCCBM: Jarosite 1.5% as raw material and 3% as set controller; Trials for Jarosite as filler at Binani Cement and Malabar Cement.	NA
14.	BZL	Study/trial on use of Jarosite in building materials	NA	Building materials like bricks, tiles, interlock bricks (CUSAT, NIIST, IMMT)	NA
15.	BZL, RRL Bh	Iron oxide from Jarosite	NA	Successful in bench scale; quality of iron oxide equivalent to commercial grade red oxide	NA
16.	CUSAT (BZL)	stabilized(fixed) jarosite in road	NA	stabilized(fixed) jarosite can be used as embankment or sub-grade material	NA

Many efforts have been made globally also for utilizing Jarosite and/or Jarosite as construction material but with limited success. The most promising and successful efforts in the country have been in cement industry and for road construction.

Chapter 6: Guidelines for Management and Handling of Jarosite

6.1 Applicability

The applicability of these guidelines has been mentioned in Section 1.2, reproduced here below:

a) All existing operational zinc smelters which are generating Jarosite.
b) Expansions of existing zinc smelters generating Jarosite.
c) New zinc smelters proposing to generate Jarosite.
d) Zinc smelters which have now got closed but generated Jarosite during their operational lifetime
e) Zinc smelters which have now switched completely to non-Jarosite options for iron residue generation but generated Jarosite in the past and still have Jarosite disposal facilities on-site (or off-site but legally the smelter's responsibility)
f) Orphan sites having Jarosite storage and/or disposal facilities
g) All stages of Jarosite, viz., the point of generation, treatment, interim storage, transportation (both on-site and off-site) up to disposal
h) Users of Jarosite whether as Jarosite or treated to produce some other product (e.g. stabilized(fixed) jarosite).

However, these guidelines are not applicable to other zinc residue options, viz., goethite/ paragoethite, haematite, neutral leach residues, pyrometallurgical options for residue treatment and disposal, etc.

6.2 Structure

The guidelines for management and handling of Jarosite are structured in the following sections:

a) Treated Jarosite and stabilized(fixed) jarosite
b) General guidelines regarding approvals required
c) Quality Control at the point of generation and after treatment
d) Treatment and temporary Storage within the smelter
e) On-site transportation
f) Disposal, operation & maintenance, capping
g) Closure & post-closure care & maintenance
h) Prevention, minimization, reuse, recycling, recovery, utilisation including co-processing
i) Off-site transportation
j) Closed sites
k) Import/Export
l) Monitoring and recordkeeping

6.3 Treated and stabilized(fixed) jarosite:

In normal course, jarosite generated from zinc smelter units is required to be treated with lime prior to sending the same any prospective utilization. SPCBs/PCCs may forward any specific utilization proposal for utilization of untreated Jarosite to CPCB for its review/comments.

Stabilized(fixed) Jarosite is produced with application of lime followed by cement or any other material to minimize the leaching potential is required for disposal in landfills as per the standards specified in Table-32.

6.4 General guidelines regarding approvals required:

a) A zinc smelter, new or expanding, proposing to generate Jarosite as the iron residue, while applying for obtaining environmental clearance (EC) under EIA Notification 2006 or updated versions thereof, shall incorporate within the EIA/ EMP report a comparative evaluation of various options and environmental evaluation thereof in support of choosing Jarosite as the residue option. It will also include the scheme for handling, treatment and disposal, including utilisation, of Jarosite including hydrogeological investigation for proposed captive disposal sites, if any, to ensure minimizing/eliminating environmental impacts therefrom.

b) The manufacturing unit shall submit the following details along with the Consent application such as:

    1) The details with regard to the ownership of the land where treated/ stabilized(fixed) jarosite pond is proposed to be constructed in accordance with these guidelines;
    2) Details of temporary storage area for storage of treated/ stabilized(fixed) jarosite, if any;
    3) Utilization plan, if any;
    4) Details of transportation (within the Zinc smelter as well as to any end user of treated/ stabilized(fixed) jarosite);
    5) Construction and completion schedule;
    6) Operational, maintenance and monitoring protocols;
    7) Remedial plans including disaster management plan; and
    8) Any other relevant information.

    SPCB/PCC shall make periodic visits to ensure that the construction, operation, maintenance of the Jarosite pond is as per the approved designs.

c) An Authorization shall be obtained from the concerned SPCB/PCC by the zinc smelters generating Jarosite and/or having Jarosite facilities on-site (or off-site, linked to the smelter and legally the responsibility of the smelter). The Authorization shall mention the requirement of treatment with lime, stabilization(fixing) of jarosite, quantity of Jarosite generated (both dry and wet tonnage), the tonnage to be disposed off including the lime and cement quantities including the targets for utilization. The options for utilization shall also be specified in the authorization.

d) Approvals shall be obtained from the concerned SPCB/PCC for the design of new or expansion of existing captive Jarosite disposal facility including compliance with siting requirements as per relevant guidelines. Adequate design measures shall be incorporated in case of specific issues in meeting siting criteria.

e) New smelters or expansion of existing smelters shall no longer be granted EC, consents or authorization for disposal of Jarosite after lime treatment (ALT) without firm commitment regarding utilisation of such Jarosite. Existing smelters disposing off Jarosite in ponds in slurry form after lime neutralization would need to ensure 100% utilisation of current generation of Jarosite within 03 years as per a scheduled prescribed by SPCB/PCCs and should strive for gradual utilisation of historical quantities of Jarosite.

f) The smelter shall submit adequate financial assurance (FA) or open an escrow account to the concerned SPCB, in a form and manner to be prescribed by it, to indemnify the State from liabilities arising out of construction, operation, closure or abandonment of the Jarosite Containment Facility (JCF), at the stage of approval for construction/expansion of the facility or at the time of approval for closure of the facility. Validity period of such FA shall be 30 years after closure. The amount of such assurance shall be based on broad guideline available at Sec 11.0 of CPCB guidelines titled "Criteria for HW Landfills", and CPCB guidelines on "Determination of Environmental Compensation….".

6.5 Quality Control at the point of generation and after treatment

The environmental characteristics of Jarosite are determined by the chemical composition and physical properties which, in turn, are determined by the quality of concentrates used in zinc extraction, the efficiency of the zinc extraction process, and the efficiency of the filtration process.

a) The zinc smelter would strive to optimize the quality and characteristics of Jarosite, as generated, so as to minimize the moisture content, acidity, total metals and soluble metal content as far as possible.

b) The smelters authorized to dispose of Jarosite after lime neutralization or stabilized(fixed) jarosite into their captive disposal facility shall ensure that they comply with the standards for landfilling as per **Table 32** below:

Table 32: Criteria for Disposal of treated/ stabilized(fixed) jarosite

Leachate parameter	Jarosite ALT, Leachate Concentration, mg/l	Stabilized(fixed) Jarosite, Leachate Concentration, mg/l
Ph	8 – 10	8 – 10
Arsenic	<1	<0.1
Lead	<2	<0.2
Cadmium	<0.2	<0.02
Chromium-VI	<0.5	<0.05
Mercury	<0.1	<0.01
Zinc	<10	<1.0

ALT: After Lime Treatment; Note: *Leachate quality is based on water leachate test i.e Leachability tests are conducted by preparing a suspension of waste and water i.e taking 100 gm of waste and filling up to 1 liter with distilled water, stirring or shaking for 24 hrs, filtering the solids and analyzing the filtrate. For this purpose, hourly samples of* treated/ stabilized(fixed) jarosite *samples will be collected, to be composited for every 24 hours.*

c) The quantity (both wet and dry basis) and quality of Jarosite as generated and after treatment (by lime or/and cement as applicable) shall be monitored on a daily basis and records maintained. The parameters to be monitored for Jarosite as generated will include the pH, soluble zinc and moisture content. The quantities of lime and cement consumed shall also be recorded and maintained.

6.6 Temporary Storage within the smelter

a) For disposal of Jarosite after lime treatment (ALT), as far as possible, no interim or temporary storage should be provided except to the extent required for the efficient conduct of the lime neutralization process.

b) Provision should be made for a facility for providing additional treatment to lime treated/stabilized(fixed) jarosite, as the case may be, in case the quality, after normal treatment, is found to be non-compliant with the direct disposal standards mentioned above.

c) Intermediate storage may be provided in case of stabilized(fixed) jarosite to render adequate time for commencement of the curing process to facilitate better handling and transport. Smelters may also explore the possibility of transporting stabilized(fixed) jarosite immediately after lime and cement mixing and provide curing at the disposal facility itself if that option is considered preferable for safe transport.

d) All facilities from the point of generation of Jarosite to the point of pumping and/or loading area and curing bay (for stabilizing), shall be designed as covered areas and with concrete/lined flooring and provision for collection of leachate and run-off.

e) Records to be maintained at the intermediate or temporary storage area: A provision of recording system to record entry of vehicle and lifting of treated/ stabilized(fixed) jarosite quantities.

f) Floor wash water, wastewater generated from vehicle washing bay, spillages of jarosite and run-off contaminated with lime-treated/stabilized Jarosite shall be collected properly and routed to Effluent Treatment Plant (ETP) or Common Effluent Treatment Plant (CETP) for treatment so as to comply with the effluent discharge norms stipulated under the Environment (Protection) Act, 1986.

g) The occupier of Jarosite is required to maintain records with regard to the Jarosite generated, accumulated quantity of lime-treated / stabilized Jarosite stored in Jarosite pond or temporary storage yard, date-wise quantity of treated / stabilized Jarosite sold or auctioned to the end users and their complete addresses and same should be provided as and when required by the regulatory authorities.

6.7 On-site transportation

a) The Jarosite after lime treatment, wherever permitted, shall normally be pumped to the Jarosite 'pond' in the form of slurry. The pumping system including the pipelines should be designed and operated/maintained in a manner so as to prevent spillages and leakages.

b) Other options of transportation can be considered, subject to adequate precautions being taken to ensure no spillage and leakage.

c) Provisions should be made to ensure immediate cleaning up in case of any spillage/leakage and such incidents should be recorded and details submitted to the SPCB/PCC concerned.

d) In case of stabilized(fixed) jarosite, transportation is normally in the form of a partially cured cake in dumpers. It shall be ensured that the dumpers used for transportation are specifically designed, operated and maintained to prevent spillages/leakages, and are not used for any other purpose.

e) Option of transporting fresh stabilized(fixed) jarosite without curing may be considered in completely closed tankers if found preferable to prevent spillages and for better curing and disposal at yard.

f) The roads used for stabilized jarosite transportation should be pucca roads (BT or CC) with adequate strength, width and berms. Drains should be provided for wash-offs from these roads and connected to a settling pond. These roads should be cleaned regularly by vacuum sweeping and washing to prevent traffic induced dust. The overflow from settling ponds should be sent to ETP for treatment and settled solids be removed and disposed off within jarosite stabilization yard.

g) The dumpers and loading equipment used for stabilized jarosite loading and transportation shall be regularly cleaned to ensure clean bodies and no dispersal of jarosite sticking to the bodies.

h) Provisions of Sections 9, 133, 134 of Central Motor Vehicles Act 1989, as amended vide Central Motor Vehicles Amendment Act 2019 shall be complied by the vehicles and drivers for transport of treated and stabilized(fixed) jarosite.

6.8 Disposal, operation & maintenance, capping

As noted in the preceding sections, there are two major options for Jarosite disposal, viz. Jarosite after lime neutralization and stabilized Jarosite. The following guidelines need to be followed regarding disposal:

i. Proposals for disposal of Jarosite after lime neutralization for new smelters or for expansion of existing smelters shall be considered only if these are associated with firm commitment for 100% concurrent utilisation of the generated Jarosite. In these plants, Stabilization of jarosite route shall be the preferred option for disposal of Jarosite in case 100% concurrent utilisation is not possible for in-operation smelters. However, new/expanded smelters can opt for mixed route, i.e., Jarosite after lime treatment to the extent concurrent utilisation is possible and stabilized / fixed jarosite for the balance quantity.

ii. Existing smelters with the option of disposal after lime treatment (ALT) will have to shift to stabilized/fixed Jarosite route within 03 years from the date of publication of these guidelines. They will be permitted to continue with Jarosite-ALT option in case they are able to utilize 100% of the current generation of Jarosite within this 5 - year period.

iii. Disposal of Jarosite ALT shall be done as per the following guidelines:

    1. Disposal shall be in a captive, on-site Jarosite Containment Facility; disposal in off-site facility shall not be permitted. A new on-site captive facilities being part of pollution control system may not warrant environment clearance (EC), provided the smelter itself has obtained an EC including the Jarosite containment facility (JCF).
    2. The captive JCF for Jarosite-ALT disposal shall comply with locational criteria mentioned at Sec 2.0 of CPCB Guidelines titled "Criteria for Hazardous Waste Landfills".
    3. Site investigations should be carried out to aid the designing of the facility, as listed in Sec 3.0 of the CPCB guidelines "Criteria for Hazardous Waste Landfills".
    4. While planning and designing the facility, the criteria listed in Sec 5.0 of the CPCB guidelines should be broadly kept in mind, to the extent applicable.

5. Wastes other than Jarosite shall normally not be permitted for disposal in the Jarosite facility, to facilitate future utilisation. Acceptance criteria for Jarosite disposal shall be as per **Table 32.**
6. The Jarosite Containment Facility (JCF) shall be designed as a double composite liner facility as detailed at Sec 7.1 of the CPCB guidelines ""Criteria for Hazardous Waste Landfills". The specifications of HDPE geomembrane and other components of liner system mentioned in the guidelines should be treated as minimum subject to the best prevailing practices and subject to other location-specific conditions. For example, thickness of HDPE geomembrane should be appropriately increased if final height of waste is planned to be more than 10 meters. Also, in view of the fact that Jarosite is to be disposed of into the facility as a slurry, and temporary covering of the pond may not be feasible, the facility should be provided with surface water pumping system to ensure that there is no or negligible surface water storage in the JCF at any time and especially during rainy season. It's critical to plan and manage the water balance across the JCF for monsoon and non-monsoon seasons, especially in high rainfall areas.
7. The design and specifications of the liner system should generally comply with the CPCB guidelines titled "Manual for Design, Construction and Quality Control of Liners & Covers", as applicable to Jarosite-ALT or stabilized/fixed Jarosite disposal.
8. The embankments of the JCF shall be constructed to ensure stable and impervious side slopes. If earthen embankments are constructed, the slopes should be made with at least 1V:2.5H slopes on both upstream as well as downstream sides with HDPE geomembrane all along the slope and proper anchoring both at bottom and at the top. In case of restricted availability of land area, steeper slopes may be specifically permitted by the concerned SPCB based on specific design measures to ensure stable slopes. In all cases, slope stability of embankments will need to be certified at design stage by an institute of repute based on the 100-year rainfall intensity, possible water collection in JCF, seismic potential of the area and other relevant factors. If height rising is required to be done subsequently, downstream method only to be used, not upstream method. Available waste materials may be used for embankment construction subject to proper evaluation of their engineering properties and taking care to incorporate adequate design measures to ensure long-term stability.
9. The smelter shall prepare an elaborate QA/QC programme for the construction stage which shall broadly comply with the requirements mentioned in Sec 7.1.4 of CPCB guidelines ""Criteria for Hazardous Waste Landfills". In addition, integrity of the geo-membrane shall be tested both at the joints and for the entire body. All design documents and records related to the QA/QC programme shall be maintained at least till the end of the post-closure period.
10. During the operational period, the leachate collected from JCF and surface water system shall be treated in effluent treatment plant and utilized within the smelter as appropriate. If required to discharge, the relevant standards should be complied as stipulated by the concerned SPCB/PCC.
11. A free board of minimum 1 meter shall always be maintained in the JCF.

12. On completion of the operational life of the JCF or on exhaustion of its capacity, the JCF should be closed/ capped following the guidelines at Sec 7.2 of CPCB guidelines "Criteria for Hazardous Waste Landfills". Before laying the cover layer, it shall be ensured that the entire free water trapped in Jarosite within the JCF has been drained and solids allowed subsiding to the maximum extent possible. The entire area of the JCF should be properly covered to prevent water entry, from the time of cessation of operations till the time top cover starts to be laid.
13. During the pre-closure period, efforts should be made to utilize the Jarosite to the extent possible.

6.9 Closure and Rehabilitation of JCF

6.9.1 Closure & post-closure care & maintenance

The smelter shall undertake closure and post-closure care of capped landfill (JCF) and maintenance activities for a period of 30 years after closure of the facility and/or landfill, broadly in compliance with Sec 9.3 of CPCB guidelines titled "Criteria for HW Landfills" and the guidelines titled "Manual for Design, Construction and Quality Control of Liners & Covers". In addition, the smelter will ensure the following:

a) That a top layer over the capping preferably of vegetative layer is well maintained with surface slopes (minimum 4H:1V).
b) That the surface drainage is not disturbed and no ponding or accumulation of water is happening anywhere on the top or in the drains.
c) That there is no or negligible leachate getting collected especially in the secondary LCS.
d) That the embankments and its slopes are kept in good condition and grass along the slopes is well maintained to ensure no erosion along the slopes.
e) If it is intended to use the top surface of the JCF, after closure, for purposes other than vegetative layer, less load bearing constructions not needing deep foundations or puncturing of capping layer such as parks, solar panels, etc. may be considered subject to a scientific risk evaluation is on possible impacts of such construction on the long-term integrity of the cover system as well as the embankments, and/or environmental/health impacts thereof and subject to approval of the concerned SPCB/PCC.

6.9.2 Rehabilitation of JCF

The main drivers for the closure and rehabilitation are:

- Eliminate contaminant runoff
- Control fugitive dust.
- Improve visual impact.
- Reintegrate with adjacent vegetated area.

The approach to JCF rehabilitation mainly follows one of two main strategies namely, (i) providing a cap or cover of soil or soil-like material to provide a plant growth medium and (ii) natural rehabilitation which refers to improving of the physical and/or chemical properties of the residue using amendments (e.g. gypsum, bio solids, or compost) followed by direct vegetation of the surface.

In case, the Jarosite generating units does not prefer for permanent closure of the existing Jarosite landfill, the unit is required to submit a proposal for the 'Existing Jarosite utilization and/or rehabilitation plan' through concerned SPCB/PCC with their recommendations to the CPCB seeking views / permission.

6.10 Prevention, minimization, reuse, recycling, recovery, utilizations including co-processing

As mandated by Rule 4 of H&OW (M&TM) Rules 2016, the zinc smelters are required to follow the hierarchy of management of Jarosite beginning with prevention and minimization. The smelters shall make efforts to:

a) Explore possibility of zinc production without generating Jarosite as the residue by adopting other options including pyrometallurgical treatment options based on a comparative evaluation of all options from techno-environmental perspective.

b) Make efforts to minimize the quantity of generation of Jarosite by improving the quality of concentrates, maximizing recovery of by-products from the residues before generation of Jarosite, operating the process efficiently, minimizing the moisture content by efficient operation of the filtration process, etc. The reduction should be achieved in specific terms, viz, Jarosite generation per tonne of zinc produced.

c) Improve the environmental characteristics of generated Jarosite by maximizing the recovery of zinc and other minor metals and by minimizing the contents of soluble metals, acidity and moisture content.

d) Explore possibility of beneficially utilizing stabilized/fixed Jarosite, preferably concurrently, for various purposes, e.g., in manufacturing of cement, in road construction, or elsewhere. **Sec 6.10.1** provides more detailed guidelines on utilization of Jarosite.

e) Explore possibility of recovering residual metals (including zinc, lead, silver, iron, etc.) from Jarosite and generate final waste preferably in the form of a slag which, in turn, can be beneficially used in cement industry or as a construction material.

f) The zinc smelter shall report on such efforts while applying for grant or renewal of consents/authorization to concerned SPCB/PCC.

6.10.1 Guidelines on utilization

A significant number of studies and research projects have been undertaken globally as well as in India to find out beneficial utilizations of Jarosite. Detailed guidelines on utilization of Jarosite are provided here below:

i. No prior permission of SPCB/PCC shall be required for sending samples of Jarosite for study/research purposes up to 5000 kg in individual cases and up to 1 MT per year. The smelter will maintain details of samples sent in Form 3 and submit details to SPCB/PCC in Form 4. Precautions shall be taken during packing and transport to ensure no spillage, leakage.

ii. **Use of Jarosite for Co-Processing in Cement Manufacturing:**

Studies have indicated that Jarosite can be beneficially used for manufacturing of cement, both as a set retarder in the cement mill, and as an ingredient in raw mix in cement kiln.

a) <u>Use in cement mill:</u>

Studies by NCCBM and others have indicated that Jarosite can be used up to 3% of Jarosite (dry basis) out of 5% of gypsum as set retarder. BIS have clarified that "----*Jarosite be permitted for use not more than 1% during grinding stage as part of the agents, as already allowed for use under the manufacturing clause under the concerned IS for cement."* Thus, separate BIS permission may not required for such application up to 1% Jarosite. As far as these guidelines are concerned, a higher proportion of Jarosite may be used subject to acceptance of the same by cement manufacturers.

b) <u>Use of Jarosite in cement kiln:</u>

Studies by NCCBM and others have indicated that Jarosite can be used up to 1.5% of Jarosite (dry basis) of raw mix. BIS have clarified that "*----the cement shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and ----"*. Thus, separate BIS permission may not be required for use of Jarosite as long as cement complying with the relevant Standard is produced.

c) No trial runs would be necessary for obtaining authorization for co-processing of Jarosite in cement kilns but will be subject to emission standards vide GSR no. 497 (E) dated 10/05/2016. Such co-processing shall be carried out as per guidelines and SOPs outlined in this document and in the July 2017 guidelines.

d) Requirements of pre-processing, in addition to those mentioned in the 2017 guidelines, will include reducing moisture content in Jarosite to the extent feasible, to ensure safe transportation and improved storage and handling at cement plant end. Pre-processing activities, including drying, storage, etc. shall be carried out in a safe manner including impervious concrete floor, covered shed, etc.

e) Grant of authorization for use of Jarosite as set retarder in cement mill shall be governed by Sec 9.0 of the 2017 guidelines and these guidelines. Trial runs and compliance with emission standards vide GSR 497 (E) shall not be applicable in such cases.

f) Jarosite for the purpose of utilisation in manufacturing of cement shall comply with criteria mentioned in **Table 32.**

iii. **Use of stabilized/fixed Jarosite in road construction**

CRRI studies recommended use of **stabilized/fixed Jarosite** in embankment (as a mixture with soil or bottom ash) or as sub-grade (mixed with soil) 50-75%. Accordingly, test patch of 300m length was constructed and performance evaluation carried out based on accreditation by IRC. Subsequent monitoring established that the test patch performed well and environmental monitoring by NEERI established no adverse impacts.

a) Accordingly, stabilized/fixed Jarosite may be used as embankment and/or sub-grade material in compliance with accreditation by IRC. Stabilized Jarosite may be used by mixing with soil in a proportion and in an encapsulated form (so as to prevent direct exposure to atmosphere and rainfall and performance evaluation of the structure shall be carried out by the user agency (State PWD/NHAI/BRO/NHIDCL/Rural road agencies, etc) or by CRRI for submission to IRC for adoption and formulation of guidelines and codes of practice for further usage in the highway sector.

b) For the purpose of utilization of stabilized/fixed Jarosite in highway sector as an embankment or sub-grade material, it shall comply with criteria mentioned in **Table 32.**

c) Environmental monitoring (soil, leachate and ground water) shall be carried out regularly around the roads/structures built using stabilized / fixed Jarosite to assess impacts, if any.

d) During construction, stabilized / fixed Jarosite shall be handled, stored and mixed in a safe manner on impervious floor and kept covered till its final usage. Transportation, storage and use of the same shall be avoided during rainy season.

e) Use of stabilized / fixed Jarosite in road construction shall be based on authorization granted by the concerned SPCB/PCC based on these guidelines and SOPs issued by concerned agencies (like CRRI. IRC, NCBM, etc.). No trial runs by CPCB/SPCBs shall be necessary for the grant of such authorization.

iv. **Other uses**

Studies have also established, at laboratory scale, the beneficial use of Jarosite to replace OPC to the extent of 12 – 13% in paste fill (for backfilling of underground mines) with curing period of 28 days, and use of stabilized/fixed jarosite as an embankment material in tailing dams. No large scale trials have been undertaken yet. Following guidelines are provided for these or other possible uses.

a) Lime treated or stabilized/fixed Jarosite for utilisation shall comply with criteria mentioned in **Table 32.**

b) Approval of the relevant regulatory agency shall be obtained before utilisation in any application. For example, approval of DGMS (Director General, Mine Safety) needs to be obtained in case of usage in paste filling or as an embankment material in tailing dam.

c) Trials may be undertaken first to undertake performance evaluation as well as environmental assessment. Such trials may be undertaken after obtaining an authorization from the concerned SPCB/PCC and under intimation to CPCB. The user agency shall submit a report of the performance evaluation and environmental assessment to the SPCB/PCC and CPCB based on which a decision would be conveyed regarding full scale usage and the precautions to be taken.

d) For trials as an embankment material in tailing dams, only stabilized/fixed Jarosite shall be used, after reducing the moisture content, in the slope portion of the embankment on the downstream side (away from the water side) in sandwich form only, i.e., with appropriate soil cover and lining.

e) Environmental evaluation shall be carried out for leachate from the mixed use, and from the actual use site. Leachate/run-off from such sites shall be reused in the mine or beneficiation plant and not discharged.

v. **Use of old treated /stabilized Jarosite:**

The smelter is required to achieve 100% utilisation for current generation of lime-treated/stabilized Jarosite on a regular basis, prior to exploring the feasibility of using old Jarosite from the Jarosite Containment Facilities(JCFs).

a) Preference should be given to JCFs which are yet to be capped.

b) Prior permission shall be obtained from the concerned SPCB/PCC for such excavation and utilisation.

c) Excavation and subsequent storage and drying, if required, should be carried out in covered shed with concrete/lined flooring and provision for collection and treatment of leachate and run-off, if any.

d) A record should be maintained, separate from that for fresh generation, of the quantity and characteristics of Jarosite thus excavated and dispatched.

e) Similar practices shall be followed for utilisation of Jarosite from closed smelters.

f) Excavation of Jarosite, for the purpose of utilisation, from the JCFs which have already been capped, can be considered and approved only after carefully weighing the benefit of eliminating a long-term risk vis-à-vis the short-term but significant risk of opening up a capped facility. The approval shall be granted by the concerned SPCB/PCC based on the precautions proposed to be taken to minimize the short-term risks.

6.10.2Recovery

There have been some attempts to recover values from Jarosite which include iron as iron oxide in addition to other metals and sulphur. Detailed reports of such attempts are not available. The following guidelines for such recovery initiatives are provided:

a) As far as possible, recovery from Jarosite should be undertaken within the smelter where Jarosite is being generated.

b) Authorization is not required for sending samples [refer 6.10.1 (i)] or for undertaking research for such efforts at laboratory scale. Amendment in consents and authorization shall be obtained for pilot or large scale trials or full scale recovery facilities. The concerned SPCB/PCC/SEIAA may determine if EC is required for such facilities.

c) The technology/process adopted for such recovery facilities shall be chosen based on minimal generation of wastes with lesser toxicity, amenability for reuse, and low secondary pollution while maximizing recovery of valuable materials/metals.

6.11 Off-site transportation

Lime treated Jarosite and/or stabilized/fixed Jarosite shall require off-site transportation, sometimes over long distances including inter-state transportation, primarily for utilisation. The responsibility for safe transport shall normally be of the generator (sender), who shall obtain the authorization for such transport, the receiver may also take such authorization and responsibility. The sender/receiver shall comply with the following requirements:

a) Lime treated Jarosite and/or stabilized/fixed Jarosite with moisture content <25 % are permitted to be transported in bulk, loose form in trucks. Trains may also be used for transporting in bulk, loose form, in a closed/covered wagons, along with other requirements as per railway norms.

b) The trucks shall preferably be dedicated for transportation of lime-treated/stabilized Jarosite and shall not be used for any other purpose

c) The trucks shall be designed such that there is no spillage or leakage during transportation, and shall be fitted with roll-on /roll-off covers.

d) Information regarding characteristics of lime-treated/stabilized Jarosite shall be provided to the transporter including how to deal with emergencies and contact details. These details will also be provided on the body of the truck in the form of a non-erasable and water proof label.

e) SPCB/PCC shall be informed regarding the planned movements of treated/stabilized Jarosite every month. SPCBs/PCCs of both states shall be informed in case of inter-state transport, including states of transit.

f) Weekly statement of trucks and quantities transported shall be submitted to the concerned SPCB/PCC with endorsement by the transporter and the receiver regarding the quantity received. Any discrepancy between quantities dispatched and received shall be highlighted and explained. Such statements shall be sent to SPCB/PCC within 7 days of the end of the relevant week.

g) Trucks used for transportation of treated/stabilized Jarosite shall comply with rules made by the Central Government under the Motor Vehicles Act, 1988 and the guidelines issued by CPCB

h) Carrying of passengers is strictly prohibited and only haulers shall be permitted in the cabin.

i) Each truck shall carry first-aid kit, spill control equipment and fire extinguisher.

j) Trucks carrying treated/stabilized(fixed) jarosite shall run only at a speed specified under Motor Vehicle Act in order to avoid any eventuality.

k) The drivers shall be minimum 10th pass (SSC) and shall possess valid driving license of heavy vehicles from the State Road Transport Authority with experience in transporting chemicals.

l) Driver(s) shall be properly trained for handling emergency situations and safety aspects involved in the transportation of treated/stabilized(fixed) jarosite. Transporter of waste, develop Emergency Response Plan (ERP) in this regard for all potential spillage/release scenarios. They should be aware of procedures outlined in Emergency Response Plan and trained on emergency spill control procedures. Requisite basic safety equipment/ Personal Protective Equipment shall be available on transportation vehicle.

m) Trucks shall be regularly cleaned including outside body and tyres at dispatch and/or receiving end to ensure no spillage or dispersal of waste en route.

n) No trans-shipment shall be permitted en-route.

6.12 Closed sites

Two kinds of closed sites are envisaged. First, smelters which are no longer in operation but have Jarosite containment facilities existing on these sites. Second category constitutes of smelters which are continuing to be operational but have old JCFs on-site. The following guidelines shall be applicable on such sites/facilities:

i. Closed smelters with JCFs

The following guidelines shall apply:

a) Lime-treated/stabilized Jarosite lying in loose outside of the JCFs, shall be transferred to JCFs.

b) An inventory of Lime-treated/stabilized Jarosite and JCFs on-site (and off-site, if any) shall be prepared including detailing of the quantities of Jarosite in each such facility, design and construction details, leachate and ground water analyses, etc.

c) Identify the actions required to be taken to ensure no long-term environmental impacts due to the Jarosite lying in the closed smelters and prepare an action plan therefor including financial implications and time schedule for implementation.

d) Submit the action plan for approval to the concerned SPCB who will consider and convey their acceptance with conditions as appropriate.

e) Implement the action plan within the agreed time frame.

f) The options for management of JCFs shall include, though not limited to, utilisation of Jarosite/stabilized-jarosite as per 6.10 above, capping as per 6.8, and/or remediation of areas within the closed site contaminated due to Jarosite. If one or more of the old JCFs were unlined or found to be contaminating the groundwater, then protective measures shall be undertaken including construction of barrier wall, pump and treat etc. Excavation of Jarosite/stabilized-jarosite from old JCFs for utilisation shall be governed by guidelines provided at Sec 6.10.1 (iv) of this document.

g) The occupier of the closed site shall be responsible for preparing and implementing the action plan as above.

h) In case of orphan sites or for such sites where the occupier is unable to prepare and implement the action plan as above on account of bankruptcy/insolvency/liquidation etc., the concerned SPCB/PCC in consultation with CPCB shall cause the action plan to be prepared by appointing a competent consultant and then get it implemented. Funds for the same shall be drawn from the escrow account created for the purpose, as mentioned in Sec 6.3(e), if available. If not, the State Government shall arrange to get the plan implemented from its environmental budget.

ii. Operational smelters with old JCFs

The occupier shall prepare an action plan as for (i) (c) above, in respect of the old JCFs.

a) Occupier shall take actions as per 6.12(i)(f) above. Priority should be accorded to explore possibility of utilizing the Jarosite from the old JCFs over and above the current generation, especially if the old JCFs are not yet capped.

b) Old JCFs may be continued to use for disposal of treated/stabilized Jarosite for the specified period (as mentioned at 6.4), only if the landfill is constructed with liner system as mentioned in these guidelines, else action as per the options given at 6.12(i)(f) shall be followed.

6.13 Import/Export

Jarosite is listed as entry no. A-1070 in Part A of Schedule III of the H&OW (M&TM) Rules, 2016. Hazardous wastes in Part-A are restricted and cannot be allowed to be imported without permission from the Ministry of Environment, Forest and Climate Change and the Directorate General of Foreign Trade license, if applicable. Following guidelines shall apply in respect of import/export of un-treated/treated/stabilized(fixed) jarosite:

a) Import of Jarosite even in stabilized/fixed form shall not be permitted
b) Export of lime-treated / stabilized Jarosite can be permitted for beneficial utilisation in the country of import only with Prior Informed Consent (PIC) of importing country.
c) All precautions shall be taken for maintaining the Transportable Moisture Limit (TML) as required for safe transportation in ships.
d) Inland transportation up to the port of export shall be undertaken as detailed in **Sec 6.10.**
e) Handling and storage in the port of export shall be undertaken with all precautions including covered storage, concrete flooring and arrangements for collection and treatment of leachate and run-off.

6.14 Monitoring and recordkeeping:

Regular monitoring and recordkeeping is critical for the success of any waste management programme and also to ensure continual improvements and take corrective steps as and when required. The monitoring and corresponding recordkeeping requirements for treated/stabilized(fixed) jarosite generators and users are listed below in **Table 33**. Additional requirements may be identified and complied, if any.

Table 33: Monitoring and record keeping requirements

Stage/material	Parameters	Frequency	Remarks
Jarosite, as generated	Moisture, pH, Soluble Zn	Hourly	For process control
Do	Total & Leachable metals	Daily	Composite of hourly samples
Jarosite-ALT	pH	Continuous, on-line	For process control
Do	Leachable metals	Daily	Composite of hourly samples
Stabilized/fixed Jarosite - fresh	Do	Do	do
Quantity generation	Total DMT, WMT, per tonne of zinc	Daily	Jarosite, stabilized(fixed) jarosite
Quantity consumed	DMT	Daily	Lime, cement
Truck details	Registration no., capacity, no. of trips, drivers, license	Daily	For on-site & off-site transportation
Leachate from JCF	Quantity, quality	Daily	Separate for primary, secondary leachates and surface pumping
Utilisation	Quantity (MT), % of generation	Monthly	Treated Jarosite, stabilized Jarosite
Samples sent	Quantity, consignee, purpose, packing	As & when required	Submit annually (Form 3, 4)
Transport details for utilisation	Truck – wise quantity, consignee, purpose,	Weekly submission to SPCB	Endorsement by consignee & transporter

Stage/material	Parameters	Frequency	Remarks
Leachate of mix used	Table 22	01 sample for every 1000 tonnes	At the site of use
Monitoring wells	Water level, pH, TDS, metals (Table 22)	1st year weekly, then monthly	Monitoring network to be designed based on hydro-geological investigation to monitor impacts of JCFs; around site of use of treated/stabilized Jarosite (by user)
Soil quality around site of use of treated/stabilized Jarosite	Metals	Pre & post-monsoon	Monitoring locations to be identified while seeking SPCB approval; baseline also required
Air quality	PM10, PM2.5, metals	As per MINAS	Around the JCFs, transport routes

The compiled data and records shall be submitted to the SPCB/PCC along with annual return (Form 4) except where otherwise mentioned.

Testing of Radioactivity in Groundwater around the Jarosite Ponds:

Radioactivity present in ground water around the Jarosite ponds should be got analyzed once in a year through AERB by the concerned Zinc smelter and analysis results is required to be submitted to the concerned SPCB/PCC as well as CPCB and for taking further action, if necessary .

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Appendix 1: Legal status of Jarosite as per the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016

<table>
<tr><td>Schedule I</td><td>Entry 7 for primary production of zinc/lead/copper ---
7.1 Flue gas dust from roasting
7.2 Process residues
7.3 Arsenic-bearing sludge
7.4 Non-ferrous metal bearing sludge and residue.
7.5 Sludge from scrubbers

Footnote to Schedule 1:
'The high volume low effect wastes such as fly ash, Phosphogypsum, red mud, Jarosite, Slags from pyrometallurgical operations, mine tailings and ore beneficiation rejects are excluded from the category of hazardous wastes. Separate guidelines on the management of these wastes shall be issued by Central Pollution Control Board".</td></tr>
<tr><td>Schedule II</td><td>Based on concentration limits: Class A (based on TCLP or STLC) in mg/l: As (5), Cd(1), Pb (5), Mn (10), Hg (0.2), Co (80), Cu (25), Tl (7), V (24), Zn (250).</td></tr>
<tr><td>Schedule III (Part A), based on Annex VIII of Basel Convention</td><td>A1020: Waste having as constituents or contaminants: Cd, Pb.

A1070: leaching residues from zinc processing, dust and sludge such as Jarosite, hematite etc.

A1080: Waste zinc residues not included on List B containing lead and cadmium in concentrations sufficient to exhibit hazard characteristics indicated in Par C of Schedule III.</td></tr>
</table>

Appendix 2: Residue Treatment

Residue treatment is the traditional name given to all processes for further treatment of neutral leach residues produced at electrolytic zinc smelters. In the 1960s and 1970s, hydrometallurgical processes were developed for precipitating high-iron containing residues, the Jarosite, the Goethite and the Haematite Processes. These follow a hot acid leach to dissolve zinc locked up in zinc ferrites and not dissolved by neutral leaching.

Prior to the development of the Jarosite, Goethite and Haematite Processes, the only processes available for recovering some of the residual zinc from neutral leach residues were pyrometallurgical. The choice was simple. Either the smelter could treat very high grade concentrates (60% Zn or more) with a low iron content (2% Fe or less) or it would suffer high zinc losses. Alternatively, the neutral leach residue could be treated pyrometallurgically to separate the zinc from the iron as a zinc oxide fume that could then be easily leached to produce more zinc sulphate for electrolysis.

The renewed interest in the old, and a search for new, pyrometallurgical processes for residue treatment, whilst being driven partly by the desire to increase zinc recovery, is now driven to a much greater extent by environmental considerations. Generally, the slags produced by the pyrometallurgical processes are more acceptable for dumping and/or civil engineering applications than the Jarosite, goethite or haematite leach residues that result from hydrometallurgical residue treatment. The various options being adopted globally are presented in **Table 34** below.

Table 34: Residue Treatment Practice

S.No	Option No.	Neutral Leach	Dump Leach Residue	Stabilize Residue	Hot Acid Leach	Residue Acid Wash	Direct Leach	Residue to ISF or Lead Smelter	Fuming Furnace	Sulphate Roast	Examples
1.	Basic Leach	YES	YES								Clarksville, Itaguai (closed), Kayseri (closed), La Oroya (part), Shenyang (from 2000 to closure in 2001), Skorpion
2.	Leach & ISF	YES						YES			Hikoshima
3.	Leach & Lead Smelter	YES						YES			Budel (from 2000), Datteln, Kamioka (to 1994), Port Pirie, Risdon, Sauget, Shenyang (to 2000), Trail
4.	Leach & Fume	YES							YES		Annaka, Boleslaw, Chelyabinsk, Crotone (closed 1999), Huize, Huludao (El), Kardjali, La Oroya (part), Leninogorsk, Liuzhou-Longcheng, Onsan, Plovdiv, Porto Vesme (to 1998), Shifang (Hongda), Shuikoushan, Szopienice (closed), Townsville (future), Vishakhapatnam (stockpile), Ust-Kamenogorsk, Vladikavkaz, Zhuzhou
5.	Jarosite	YES	YES		YES	OPT					Baiyin North West, Cajamarquilla, Chifeng, Juiz de Fora, Kamioka (1994-2000), Liuzhou-NF, Mian Xian (Bayi), Nordenham, San Luis Potosi, Risdon (until 1997), San Juan de Nieva (to 2001), Sukpo, Tak, Torreon, Tres Marias, Xiangfen

6.	Jarosite Variant	YES	YES		YES						Binanipuram, Budel (until 2000), Cartagena, Debari, Kidd Creek, Kokkola, Odda, Porto Vesme (from 1999), San Juan de Nieva (to 2001), Valleyfield (until 1998), Vishakhapatnam (from 2000)
7.	Jarosite & Stabilize	YES	YES	YES	YES	OPT					Chanderiya (El), San Juan de Nieva (from 2001), Valleyfield (from 1998)
8.	Paragoethite	YES	YES		YES						Springs
9.	Goethite	YES	YES		YES						Auby, Balen, Bartlesville (closed), Kamioka (from 2000), Overpelt (closed)
10.	Haematite	YES			YES						Iijima, (Abandoned by Balen, Datteln & Tres Marias)
11.	Basic Leach & Sulphate Roast	YES	YES							YES	Akita (closed)
12.	Concentrate Pressure or Atmospheric Leach	YES	YES				YES				Balkhash, Flin Flon, (in part Kidd Creek, Kokkola, Odda, Onsan, Trail)

Option 1: Basic Leach (i.e. no Residue Treatment)

Three operating smelters fall into this category relying on an acceptable recovery by treating low-Fe concentrates and on the ability to dump a leach residue on, or close to, the smelting site.

Option 2: Leach and ISF

One smelter falls into this category, Hikoshima (Japan). This option has the advantage that no residues are dumped on site but the disadvantage of relying on others to treat its residue pyrometallurgically, at a considerable cost.

Option 3: Leach & Lead Smelter

There are six operating smelters in this category. At two smelters, the residues are treated at the on-site lead smelters. At another smelter, the neutral leach residue is further processed to a lead-silver residue for treatment at a lead smelter elsewhere while paragoethite is treated at a third lead smelter.

Option 4: Leach & Fume

Eighteen smelters fall into this category. At two smelters, a paragoethite residue is produced for fuming, whereas all the others carry out fuming after only a basic neutral leach. The Waelz process dominates as the fuming method. Onsan (S. Korea) has adopted the Ausmelt process and the combined flowsheet, even with high-Fe concentrates, can achieve zinc recoveries as high as 97%. One disadvantage is that most of the precious metals in the leach residue pass into the Waelz kiln slag. The fume from this processing route frequently contains enhanced levels of indium, which can then be recovered as a valuable by-product.

Option 5: Jarosite

The Jarosite Process with dumping of residues is popular. This is a reflection of the fact that, of all the hydrometallurgical processes, metal recovery is the highest and costs are the lowest. Risdon ceased Jarosite dumping in 1997 and moved to Option 3. However, Porto Vesme, which previously produced paragoethite, changed to Jarosite Variant (Option 6) in 1998 in order to enable Waelz kiln capacity to be used for treating other materials.

Option 6: Jarosite Variant

Compared with Option 5, this option (either the Outokumpu Conversion Process or the Reverse Jarosite) offers exceptional metal recoveries, but without the option of lead-silver recovery, in a compact process.

Option 7: Jarosite & Stabilize

This option involves the stabilized(fixed) jarosite process whereby Jarosite residues are stabilized with cement before dumping in a form that meets standards for environmental leaching. CEZ Valleyfield, which developed this stabilization process, uses a Reverse Jarosite variant, where production of a separate lead-silver residue is not possible. However, the stabilization process could be applied to Jarosite produced by the standard process allowing the production of a lead-silver residue. The new smelters of HZL at Chanderiya and Dariba use the process of stabilizing (fixing) jarosite.

Option 8: Paragoethite

Only one smelter falls into this category of Paragoethite and dump, emphasizing the fact that recoveries are lower and costs higher than for the Jarosite Process. This smelter may adopt a pyrometallurgical route for residue treatment in future.

Option 9: Goethite

Three smelters have used the Goethite Process with no further treatment.

Option 10: Haematite

Only Iijima has adopted and continued with the Haematite Process. The potential advantages of haematite are that the tonnage produced is less than for any of the other hydrometallurgical processes as the iron content can be as high as 60%, and there is potential to use the product in cement manufacture. Iijima sells haematite for cement production. The process also offers the opportunity to achieve good recoveries of lead and precious metals.

Option 11: Basic Leach and Sulphate Roast

Only Akita (now closed) adopted this route, and this followed the abandoning of the Electro-thermic process for residue treatment. Sulphate roasting requires the use of large quantities of pyrite at considerable cost. However, the calcine produced is easily leached for zinc.

Option 12: Pressure Leach

Several smelters (Kidd Creek, Kokkola, Odda, Onsan and Trail) have a pressure or atmospheric concentrate leach section to augment production, and the residues subsequently join the other leach residues for treatment. Only two smelters, Flin Flon (Canada) and Balkhash (Kazakhstan), adopt pressure leaching for 100% of their feed. The main driving force for Flin Flon was the elimination of sulphuric acid production and this is stated as a major advantage for Balkhash. The process achieves high recoveries. Residues at Flin Flon are dumped with mine tailings but, in principle, any of the conventional iron residues could be produced.

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